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FINAL REPORT

on

A STUDY TO DEVELOP A MECHANIZED WELDING PROCEDURE TO JOIN THICK-GAGE ALUMINUM ALLOY PLATE USING NARROW-GAP TECHNIQUES

to

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS8-11102

by

D. E. Conklin, R. P. Meister, R. E. Monroe,
and D. C. Martin

January 31, 1965

BATTELLE MEMORIAL INSTITUTE
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Columbus, Ohio 43201

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A STUDY TO DEVELOP A MECHANIZED WELDING PROCEDURE TO JOIN THICK-GAGE ALUMINUM ALLOY PLATE USING NARROW-GAP TECHNIQUES

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D. E. Conklin, R. P. Meister, R. E. Monroe,
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INTRODUCTION

This report describes research done under Contract NAS8-11102 to evaluate the use of the Narrow-Gap welding process for joining aluminum. The objective of this program was to develop procedures for Narrow-Gap welding thick-gage 2219 aluminum plate in the flat, vertical, and horizontal welding positions.

The Narrow-Gap welding process was conceived and developed at Battelle under Bureau of Ships Contract NObs-86424 for welding thick steel plate in all positions. Equipment is now being developed to apply this process to automatic welding of submarine hulls. The many advantages of the Narrow-Gap process make it attractive for welding thick aluminum plates.

The most distinguishing feature of the Narrow-Gap process, as implied by its name, is the use of a narrow square-groove butt joint rather than a conventional vee or U-groove joint normally used for welding thick plate. The normal joint width used for Narrow-Gap welding is about 1/4 to 3/8 inch. The weld is deposited using the inert gas-shielded consumable electrode process. Special small-diameter contact tubes are used to conduct welding current and guide the small-diameter filler wire into the bottom of the narrow weld joint. Either a single bead or a double bead is deposited in each weld layer. The narrow joint and small weld pool allow the process to be used for out-of-position welding.

Some of the advantages of Narrow-Gap welding are described below:

(1) Narrow-Gap welds can be made out of position since the weld pool is small and is more easily controlled. There is no need to position large structures which could mean large savings in tooling costs.

(2) The Narrow-Gap process is adaptable to completely automated operation. The process is inherently a machine operation, so it can be readily set up to gain the speed and precision of automation.

(3) There is a substantial saving in filler wire cost when the Narrow-Gap process is used. Figure 1 shows a tracing of the cross section of an actual twin-wire Narrow-Gap weld in 5-inch aluminum superimposed on a drawing of a typical joint design used by an aerospace manufacturer for gas-metal-arc welding of aluminum. Over 3-1/2 times more weld metal is required to fill the standard double vee joint than is required for the Narrow-Gap joint.

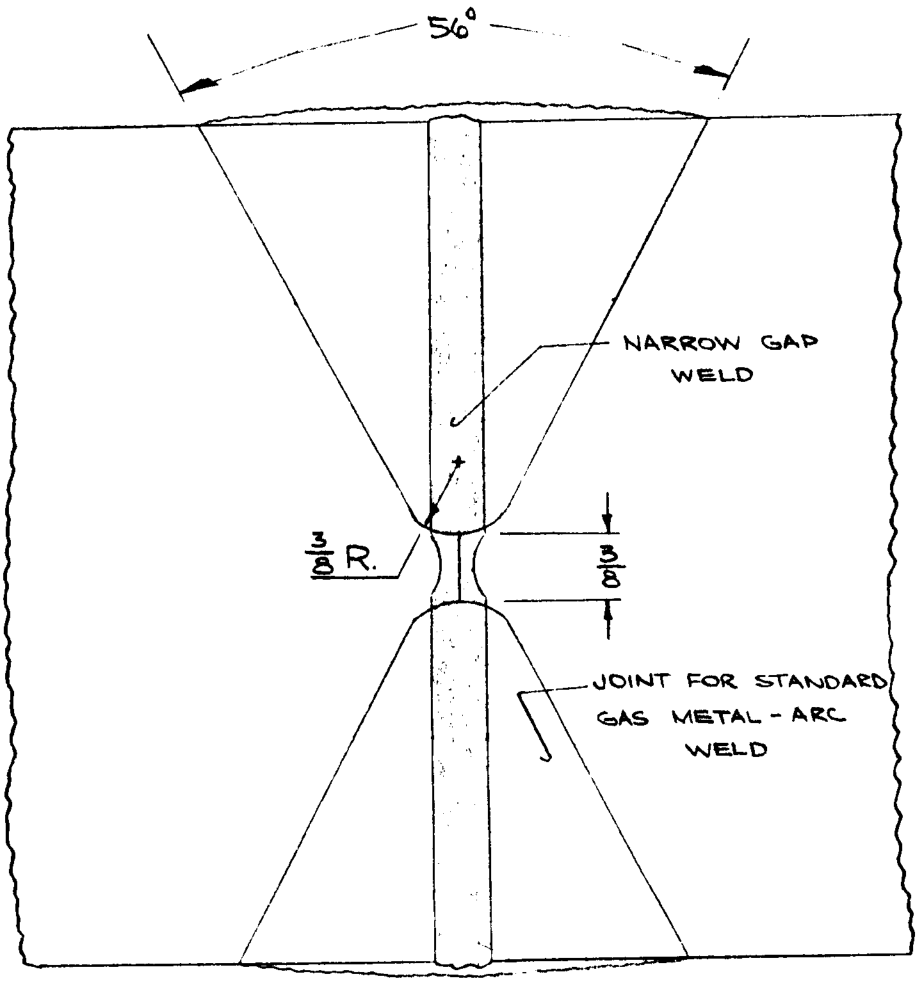

FIGURE 1. COMPARISON OF TRANSVERSE SECTION IN NARROW-GAP AND TYPICAL STANDARD JOINT FOR GAS-METAL-ARC WELDS IN 5-INCH-THICK ALUMINUM

(4) The weld-finishing rate in thick plate is substantially higher for Narrow-Gap welds than for gas-metal-arc welds made using conventional joints. The specified wire input for welding the standard joint shown in Figure 1 is 0.090-inch-diameter wire at a wire-feed speed of 163 ipm. This corresponds to a deposition rate of 6.52 pounds per hour, based on 1500 inches of wire per pound and 100 percent arc transfer. Twin-wire Narrow-Gap welds in 5-inch-thick plate were deposited using a 3/64-inch-diameter wire with a total wire feed rate of 645 ipm on the two welding heads. The deposition rate in this Narrow-Gap weld is then 6.6 pounds per hour based on 5880 inches of wire per pound. Since the deposition rate is about the same for the two processes, the finishing rate of the Narrow-Gap weld is about 3-1/2 times faster than that of the conventional weld because of the smaller volume of metal required to fill the Narrow-Gap joint.

(5) There is less shrinkage and distortion with the Narrow-Gap process because of the reduced volume of weld metal and the balanced weld shape.

(6) Narrow-Gap welds have a more favorable welding residual-stress distribution as a result of the very narrow welds.

(7) The machining and joint fit-up tolerances for Narrow-Gap joints is less critical than those for electron beam EB welding. EB welds are made using a square-butt joint preparation with no gap. Very slight gaps in the joint, in the order of 0.005 inches (depending on thickness being welded) can cause poor welds. Also, the Narrow-Gap process can weld thicker plates than are presently weldable using EB welding.[(1)*]

The research has shown that the Narrow-Gap process can be used to join 2219-T31 aluminum alloy plates in the flat, vertical, and horizontal positions. Narrow-Gap Welds were made on plate thicknesses up to 5 inches. Weld tensile strengths of 40-42 ksi were obtained. The research has indicated that, with further development of equipment, it may be possible to weld plates thicker than 5 inches by the Narrow-Gap process.

The greatest economy of the Narrow-Gap process is realized when welding heavy thicknesses such as the Y-rings in the Saturn booster. However, since the Narrow-Gap process can be automated, and can be used for out-of-position welding, it may be advantageous for welding thinner plate used in the various tankage components.

SUMMARY

A study was conducted to develop Narrow-Gap welding procedures for joining thick-gage 2219 aluminum alloy plate.

The plate material used in this study was 1-, 2-, 3-, 4-, and 5-inch-thick 2219-T31 aluminum alloy plate furnished by the George C. Marshall Space Flight Center. The welding wire used was 3/64- and 1/16-inch-diameter 2319 aluminum alloy wire obtained from commercial sources. Welding grade helium and argon were used for shielding.

*See Bibliography.

The basic welding equipment setups used in this program were made up of commercial gas-shielded metal-arc welding components. A number of modifications were made to the commercial-welding equipment as required to produce satisfactory Narrow-Gap welds. These modifications included changes in contact tube configuration, improvement of the wire-guide system to support the wire and to provide controlled wire cast and modification of the gas-shielding system to obtain good shielding at the bottom of the narrow groove.

A number of different joint designs were used during this program. For welds made from one side of the plate, the joint design consisted of either a square-butt joint with a backing strip or a narrow U-joint with parallel sidewalls. The joint designs used on plates welded from 2 sides were double-U joints with 0 to 6-degree included angles.

Three different Narrow-Gap techniques – the single-wire-centered, the single-wire offset, and the twin-wire technique – were used for depositing welds. In the single-wire-centered technique, the filler wire is centered in the joint. Each weld layer consists of a single weld bead which completely bridges the narrow groove joint. In the single-wire offset technique, a bead is deposited alternately to one side of the joint, then the other. Two weld beads are deposited in two passes to complete each layer of the weld. In the twin-wire technique, two arcs operate in tandem in the joint with each offset from the joint center line toward opposite sidewalls. Each weld layer is made up of two weld beads which are deposited in a single weld pass.

The welding conditions were set by varying the welding parameters over a wide range. In general, the welding conditions for the thinner plates were developed first; then studies were started on welding the thicker plates. Also, the flat position welding studies generally preceded the horizontal and vertical position studies.

Good welds were made in 1-inch-thick plate while shielding with standard commercial nozzles, but it was necessary to develop improved shielding for welding plates thicker than 1 inch. Shielding efficiency studies were conducted on mock-ups of proposed nozzle designs. A visible vapor was used to indicate gas flow patterns in a transparent Narrow-Gap joint. Shielding nozzles developed by this method were then evaluated by using them while welding.

Testing during this program consisted of visual observations, radiographic examination, metallographic examination, hardness tests, tensile tests, and bend tests.

The important findings made in this program were as follows:

(1) Aluminum plate between 1 and 5 inches thick can be welded satisfactorily by the Narrow-Gap process.

(2) Recommended Narrow-Gap procedures were developed for (a) welding 1 to 3-inch-thick 2219 aluminum plate in the flat position by the single-wire-centered technique; (b) welding 1 to 5-inch plate in the flat position by the twin-wire technique; (c) welding 1 to 2-inch-thick plate in the horizontal position by the single-wire-centered technique; and (d) welding 1 to 5-inch-thick plate in the vertical position by the twin-wire technique.

(3) The effects of various welding paramters on the quality of Narrow-Gap welds were determined.

(4) Transverse weld-tensile strengths in Narrow-Gap welded 2219-T31 aluminum alloy compare favorably with tensile properties obtained in joints welded by other processes. Tensile joint efficiencies as high as 76 percent were obtained in tests using small specimens in the as-welded condition. Higher joint efficiencies would be expected in full-section tests of material aged to the T-81 condition.

(5) Welds meeting or exceeding the Class 2 radiographic requirements of MSFC-SPEC-259 were obtained with the Narrow-Gap welding procedures. As expected, the efficiency of the gas-shielding nozzles was found to have a significant effect on weld quality (notably porosity). Improved special shielding nozzles for use with the Narrow-Gap process were developed.

(6) Very narrow heat-affected zones were measured in Narrow-Gap welds deposited with the recommended procedures. The heat-affected zone width in Narrow-Gap welds is probably narrower than in electron-beam welds.

(7) Unfused areas in some welds were related to low-joint strengths. Such defects were essentially eliminated in the final recommended welding procedures.

(8) A marked similarity in the properties and characteristics of Narrow-Gap and electron-beam welds[1] in comparable thicknesses was observed. This similarity is not unexpected considering the similar weld profile, but is totally unexpected considering the very different welding procedures. Either process appears to offer improvement over conventional gas-shielded methods in welding heat-treated aluminum alloys. An obvious advantage of Narrow-Gap welding is the freedom from restrictions imposed by the vacuum chambers needed in electron-beam welding.

The following sections of this report describe materials, equipment, procedures, special components, recommended procedures, a detailed discussion of results, conclusions, and recommendations. Welding experiment data are given in tabular form in Appendix A.

MATERIALS

Plate

The plate material welded during this program was 2219 aluminum alloy furnished by the George C. Marshall Space Flight Center. The plate was supplied in 1-, 2-, 3-, 4-, and 5-inch thicknesses in the -T31 condition (now called the -T351 condition in thicknesses greater than 2 inches).

The aluminum alloy 2219 is a relatively new high-strength, heat-treatable commercial alloy intended for use where elevated-temperature strength is required. It is noted for its good weldability and stress-corrosion resistance. The chemical composition, temper, and mechanical properties for 2219 plate are specified by MIL-A-8920-A(ASG), 20 May 1963. The specified chemical composition of 2219 aluminum alloy is given below:

(Percent Maximum Except Where Indicated as a Range)

Si	Fe	Cu	Mn	Mg	Zn	Ti	V	Zr	Others Each	Others Total	Aluminum
0.20	0.30	5.8-6.8	0.20-0.40	0.02	0.10	0.02-0.10	0.05-0.15	0.10-0.25	0.05	0.15	Remainder

The temper designation -T31 is specified for 2219 alloy that has been solution heat treated and cold worked by flattening or straightening operations. The temper designation -T351 presently used for plate over 2 inches thick is specified for 2219 alloy that was solution heat treated, stress relieved by stretching to produce a set of 1-1/2 to 3 percent, with the plates receiving no straightening after stretching. (The typical solution heat treatment used by Alcoa is heat treating to 1000±10 F and quenching in cold water.) The required tensile properties of 2219-T31 aluminum alloy in the "long transverse" direction (parallel to the plate surface, perpendicular to the direction of rolling) are shown below:

Temper and Form	Thickness, inch	Tensile Strength Minimum, psi	Yield Strength, Minimum, psi, 2.0 Percent Offset	Elongation, 2 inches or 40 percent (minimum)
-T31 (flat sheet)	0.040-0.249	46,000	28,000	10
-T351 plate	0.250-2.000	46,000	28,000	10
(formerly -T31 plate)	2.001-3.000	44,000	28,000	10
	3.001-4.000	42,000	27,000	9
	4.001-5.000	40,000	26,000	9
	5.001-6.000	39,000	25,000	8

Standard 0.505 round tensile specimens were prepared and tested from 2 and 5-inch-thick 2219-T31 aluminum alloy plate that was received for this program. All specimens were taken parallel to the plate surface. The results of these tests are shown below:

Plate Thickness, inches	Direction of Test		Elongation, percent in 2 inches	Percent Reduction Area	Yield Strength, 0.2 Percent Offset, psi	Tensile Strength, psi
2	Perpendicular to rolling direction		20.0	35.8	33,750	55,900
			20.8	32.6	28,940	54,320
		Avg.	20.4	34.2	31,345	54,110
5	Parallel to rolling direction		26.0	38.3	39,500	57,810
			24.5	42.8	39,390	57,560
		Avg.	25.2	40.6	39,445	57,680
5	Perpendicular to rolling direction		20.0	36.4	33,750	57,250
			20.0	32.4	33,830	57,410
		Avg.	20.0	34.4	33,790	57,330

These data indicate that the tensile properties of the 2 and 5-inch plates surpass the requirements of the military specification.

Other material tempers of 2219 aluminum originally planned for inclusion in this program were not available.

Welding Wire

All test welds were made using 2319 aluminum alloy wire. This wire was developed for use in gas-metal-arc welding 2219 aluminum alloy sheet and plate. The 2319 welding wire for this program was purchased from a commercial supplier. This filler wire was received level wound on plastic spools with about 15 pounds of wire on a spool. The spool was packaged along with a dessicant in a hermetically sealed container.

The chemical composition of 2319 alloy specified by the supplier is:

(Percent Maximum Except Where Indicated as a Range)

Si	Fe	Cu	Mn	Mg	Zn	Ti	Be	V	Zr	Others Each	Others Total	Aluminum
0.20	0.30	5.8-6.8	0.20-0.40	0.02	0.10	0.10-0.20	0.0008	0.05-0.15	0.10-0.25	0.05	0.15	Remainder

The specified chemical compositions of the wire and plate differ only in the higher titanium content in the 2319 wire.

Shielding Gas

Mixtures of helium and argon were used for shielding. These gases were of commercial welding grade. They were purchased separately in steel cylinders, then mixed in a manifold before being delivered to the welding torch.

EQUIPMENT

Equipment used during this study included basic welding setups, special equipment components, and instrumentation.

Basic Welding Setups

Three different basic welding setups were used for welding during the performance of this program. Each of these setups consisted of the following:

(1) A gas-metal-arc welding head (wire-drive motor) and controls
(2) Welding barrel (torch)
(3) A traversing mechanism
(4) A power supply to provide welding current.

Each of the three basic equipment setups is described below.

Setup A - Single Welding Head on Fixed-Position Sidebeam Carriage

Standard commercial equipment arranged in a conventional setup was used to make most of the single-wire narrow-gap welds. This setup consisted of:

(1) A Hobart Model 16DA-2044B welding head with Hobart controls
(2) Air Reduction-Aircomatic Model 60-A Welding Barrel Assembly
(3) A Linde OM-48 sidebeam carriage mounted on a fixed beam
(4) A Hobart 500-ampere constant-potential motor generator.

The welding head and carriage are shown in Figure 2.

The Hobart wire-feed system has no feedback control. The wire-feed speed of this system, therefore, may vary with varying load or line voltage. The Hobart system has a feature, however, that is valuable in welding aluminum. It has two pairs of drive rolls (four driven rollers) instead of the single set of rolls used on most systems. The dual set of rolls applies a greater feeding force without deforming the soft aluminum wire.

The Linde OM-48 sidebeam carriage used in this setup was equipped with a Type O electronic governor to maintain travel speed within ±1 percent.

Setup B - Single Welding Head on All-Position Sidebeam Carriage

Vertical welding was started with a setup consisting of:

(1) An Aircomatic Model AMH-B welding head with an AMC-C control
(2) Aircomatic Model 60A Welding Barrel Assembly
(3) An all-position sidebeam carriage built at Battelle
(4) A constant-potential power supply.

The wire-drive system used in this setup had an electronic speed regulation so that the speed could be maintained within a few percent. This wire-drive system had only one set of drive rolls instead of dual sets of rolls as on the Hobart drive unit. The Aircomatic wire-drive system did have the feature, however, of rubber mounting between the hub and the rim of the drive rolls. This elastic mounting of the rolls kept them in firm contact with the wire; yet the squeeze force of the rolls was not enough to deform the soft aluminum.

An all-position sidebeam-carriage system was built at Battelle to provide precision controlled travel for machine welding.* The framework of this machine is extremely rigid. A large lead screw transmits power to drive the carriage. Power is provided by a 1/2-horsepower Servo-Tek motor with dynamic braking and tachometer feedback control. The tachometer-feedback-control system keeps the preset travel speed substantially constant (within ±5 percent) even though there are changes in line voltage, motor torque, and motor temperature.

The sidebeam carriage can be changed from the flat position to the vertical or overhead position. The sidebeam swivels on a ball-bearing mounted shaft and can be locked at any angle from horizontal to vertical.

*This carriage was not built as a charge to the NASA contract.

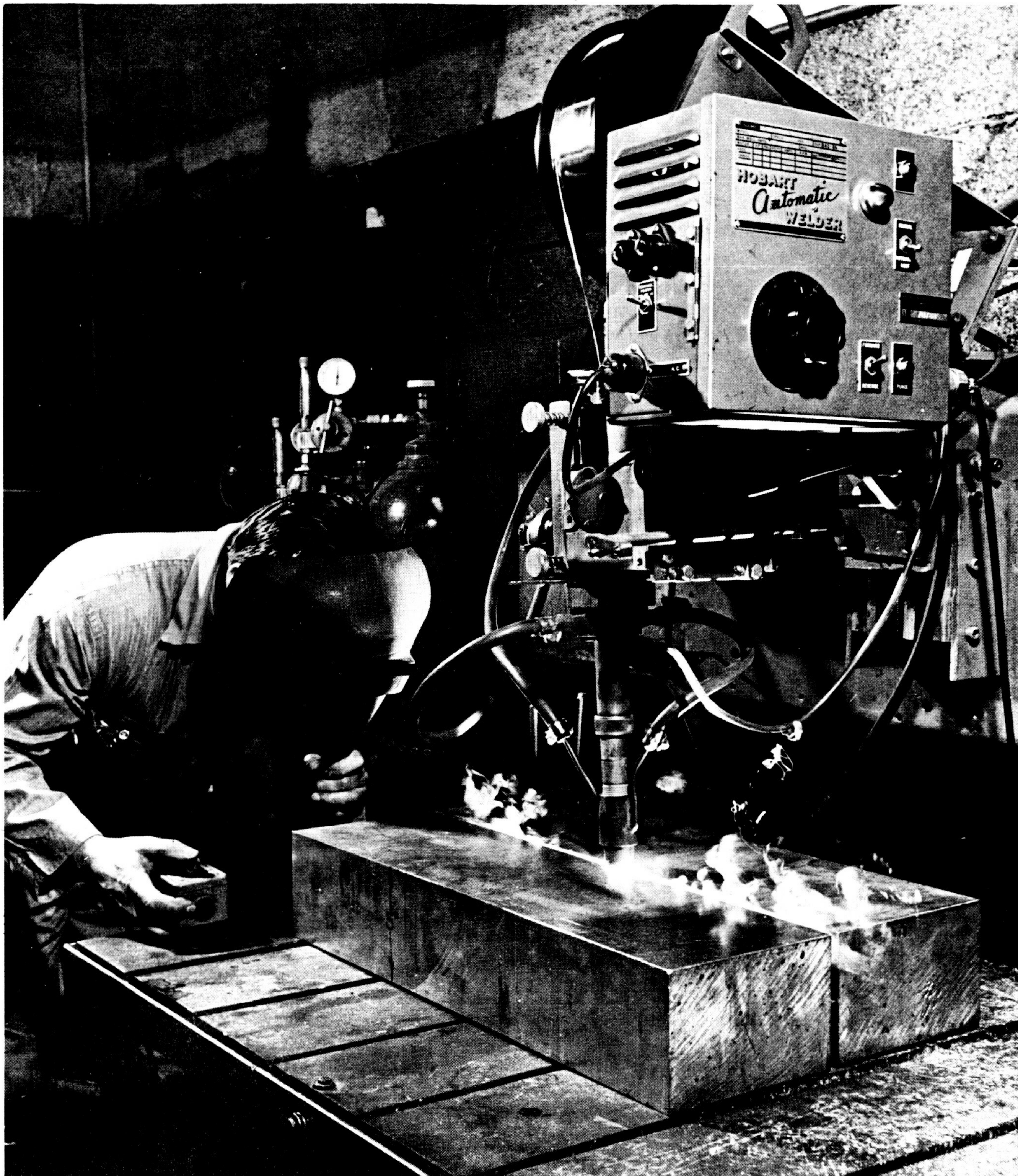

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FIGURE 2. BASIC WELDING SETUP FOR NARROW-GAP WELDING BY THE SINGLE-WIRE TECHNIQUE IN THE FLAT POSITION (SETUP A)

For equipment Setup B, two different constant-potential power supplies were used. A Hobart 500-ampere motor generator and a Vickers 400-ampere rectifier unit were used interchangeably with no significant difference in welding results.

Setup C - Dual Welding Heads on All-Position Sidebeam Carriage

All twin-wire welding was done on a setup consisting of:

(1) Two Aircomatic AMH-B welding heads with modified AMC-C controls
(2) Two Aircomatic Model 60A welding barrel assemblies
(3) The Battelle-built all-position sidebeam carriage system
(4) Two Vickers 400-ampere constant-potential rectifier power supplies.

Figure 3 shows this twin-wire welding setup in the vertical welding position. The welding barrels were mounted in tandem so that they were spaced about 1-1/4 inches apart along the direction of travel. They were arranged so that they could be individually adjusted to establish contact-tube-to-work distance and lineup in the joint. A separate power source provided current for each wire.

The electronic controls were modified to provide the necessary interrelationship of the two welding-control systems and the travel-control system. The two wire-drive systems were electronically sequenced so that the wire drive, and hence arc initiation, on each wire could be started at the same place in the joint. The leading wire drive started when the welding head travel started; an adjustable time-delay system then caused the training wire drive to start after a preset time. The wire-drive systems could also be sequenced to stop at the same place in the joint.

The change from the single-wire Setup B to the twin-wire Setup C required little visible change in the weld head equipment, other than the addition of a second welding head.

Special Equipment

Considerable effort in this program was spent in modifying some of the components of the basic equipment setups described above. These modifications were necessary to effectively control the electrode position and to obtain adequate gas shielding in the narrow groove.

A number of contact tip and shielding nozzle designs were evaluated during this program. In addition, modifications were made to the wire-drive system to provide adequate wire support and to improve wire positioning by controlling the wire cast.

These special equipment modifications are discussed later in this report.

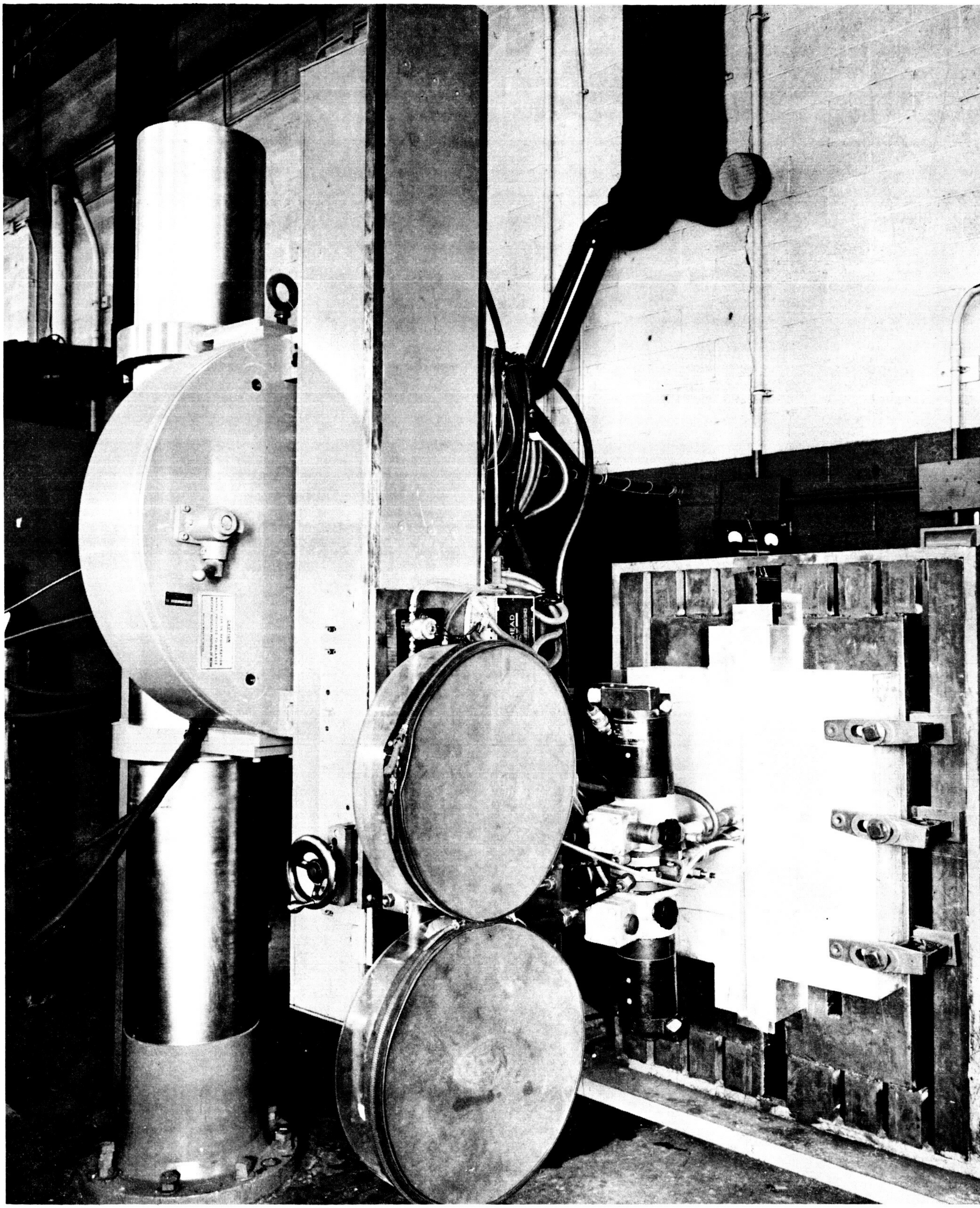

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FIGURE 3. BASIC WELDING SETUP FOR TWIN-WIRE WELDING IN THE VERTICAL POSITION

Special equipment modifications were later added to this equipment.

Instrumentation

Esterline-Angus recording meters were used to record welding voltage and current.

Wire-feed-speed controls were initially calibrated by making actual wire feed measurements. Wire-feed speed was set using the calibrated control settings prior to making each weld. Periodic checks were made of the wire feed control calibration. The control settings were found to be accurate within ±5 percent. Since welding current is dependent on wire-feed speed, other parameters being constant, final adjustments in wire feed were made according to current requirements.

Weld interpass temperature and preheat, when used, was measured using a Pyrocon contact pyrometer.

EXPERIMENTAL PROCEDURES

The experimental procedures used during this program are discussed in the following sections of this report.

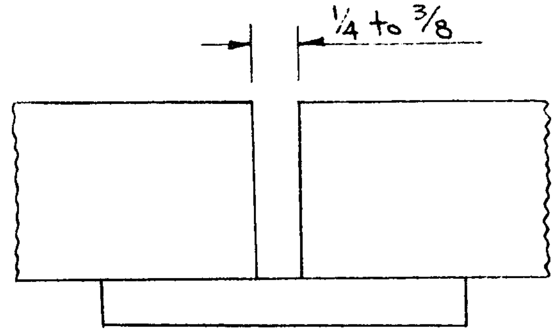
Preparation for Welding

The aluminum plates were cut to size using a band saw with no lubricant. Joint preparations were machined either by shaping or milling, also without lubricant. Before joint fitup, the joint surfaces and the adjacent plate surface, within 1/2 inch from the edge of the joint, were wiped with acetone and draw filed or scraped.

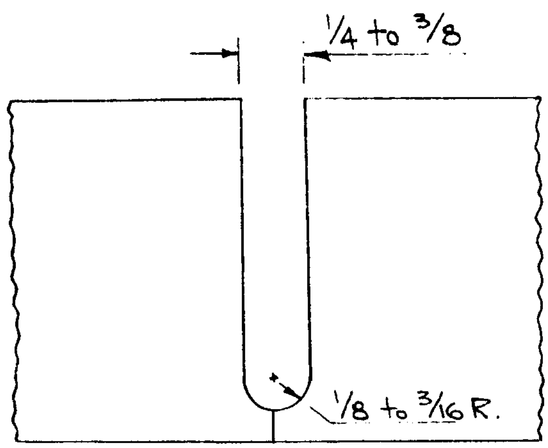
Sketches of the two joint designs used for welding 1-, 2-, and 3-inch plate thicknesses are shown in Figure 4. When Joint Design A, with the backing strip, was used, the edges of the two plates were spaced to obtain the proper joint gap and the backing strip was tack welded to the plates. Joints without a backing strip were not tack welded. The plates were simply clamped in place.

All welds in 1 to 3-inch plate thicknesses were deposited from one side. Plates were set up for welding by clamping them to a table top made up of 1-inch-thick steel plate or steel channels. The plates were prepositioned to obtain a 2 to 4-degree included angle in the joint to allow for joint pull-up. Figure 5 shows a 3-inch 2219 aluminum plate setup for welding using Joint Design B.

Welds in 5-inch-thick plate were made using a double U joint design. Three variations of the double U joint preparation are shown in Figure 6. No prepositioning was required on 5-inch plate welds since the joint pull-up was balanced by welding alternately on opposite sides of the plate. The test plate was clamped to a table top which could be rotated around a horizontal axis. Both sides of the joint were accessible for welding so that the table top could be turned over and the plate welded from either side.



JOINT DESIGN A - BACKING STRIP JOINT



JOINT DESIGN B - U-GROOVE JOINT

FIGURE 4. JOINT DESIGNS USED FOR NARROW-GAP WELDING 1-, 2-, AND 3-INCH-THICK 2219-T31 ALUMINUM ALLOY TEST PLATES

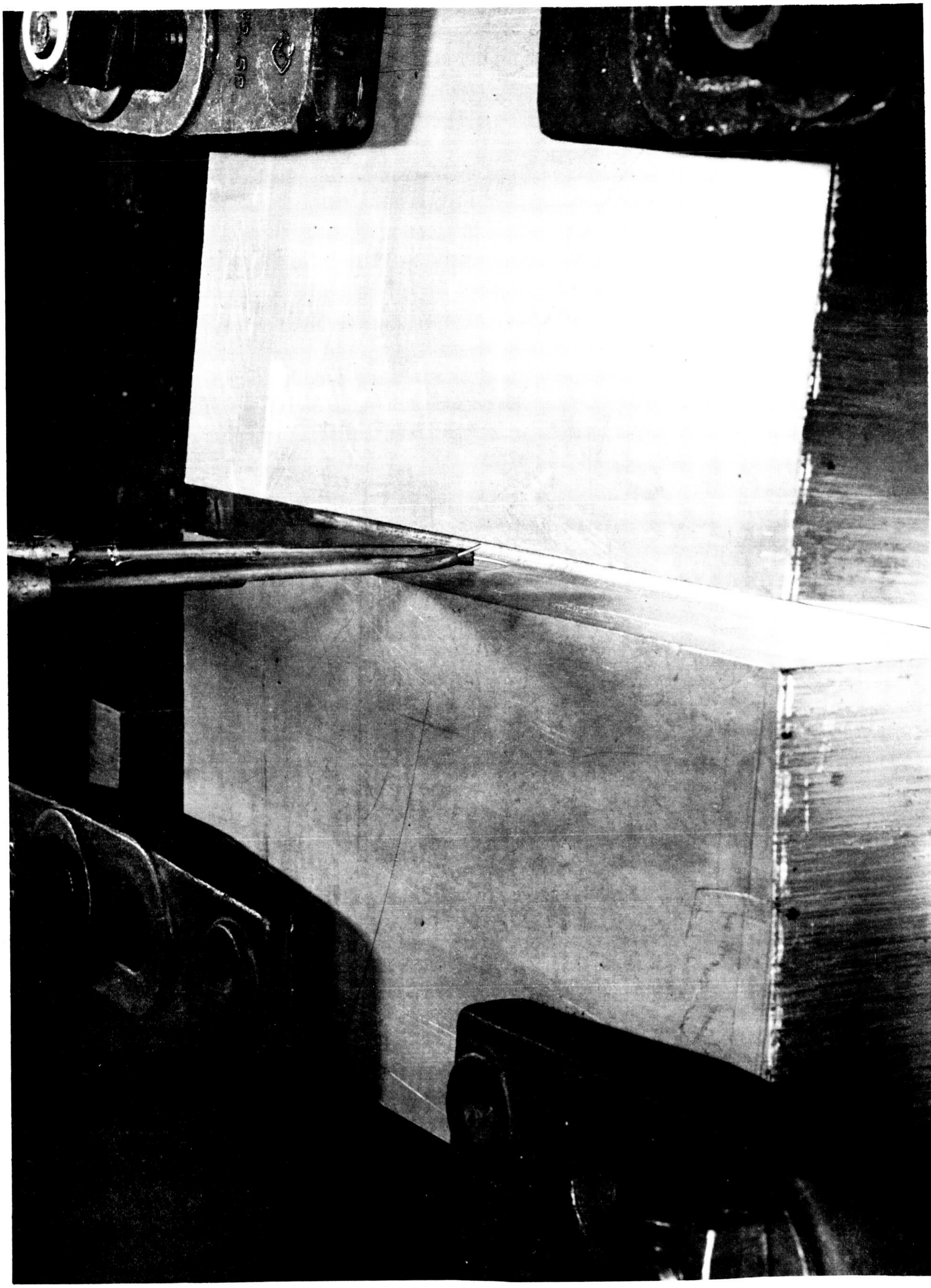


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FIGURE 5. SETUP FOR NARROW-GAP WELDING 2219 ALUMINUM PLATE FROM ONE SIDE USING THE TWIN-WIRE TECHNIQUE

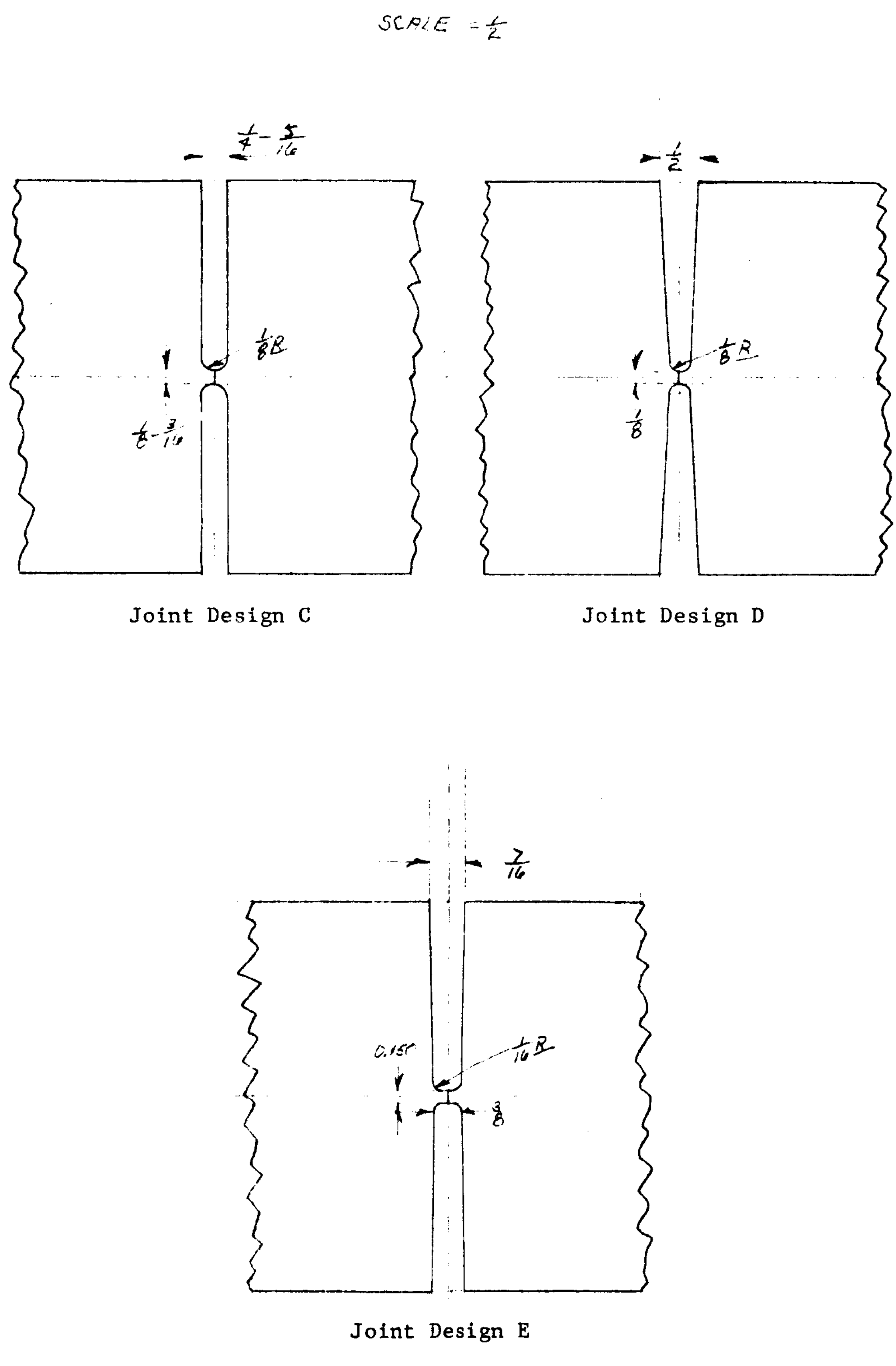


FIGURE 6. JOINT DESIGNS USED FOR NARROW-GAP WELDING 5-INCH-THICK 2219-T31 ALUMINUM ALLOY TEST PLATES

A number of restraint test welds were made in 5-inch-thick plate to evaluate the crack susceptibility of welds. These restraint test welds were deposited in 2-1/4-inch-deep x 5/16 to 3/8-inch-wide grooves milled into the 5-inch-thick plates.

Welding Techniques

Three different techniques were used for depositing Narrow-Gap welds. As shown in Figure 7, these three techniques differ in the weld bead sequence used to deposit the weld. The three techniques are called the single-wire-centered, the single-wire-offset, and the twin-wire technique.

In the single-wire-centered technique, the filler wire electrode is centered in the joint to deposit a weld bead which fuses to both sides of the joint (see Figure 7a). Each weld layer consists of a single weld bead.

In the single-wire-offset technique, the electrode is offset to one side of the joint. A fillet-type bead is deposited alternately to one side of the joint and then the other. Two weld beads are deposited in two passes to complete each layer of weld as shown in Figure 7b.

In the twin-wire welding technique, two arcs operate in tandem in the joint. The lead and trail wires, spaced approximately 1-1/4 inches apart, deposit a fillet-type bead on opposite sides of the joint. Each weld layer is made up of two weld beads deposited in a single pass (Figure 7c).

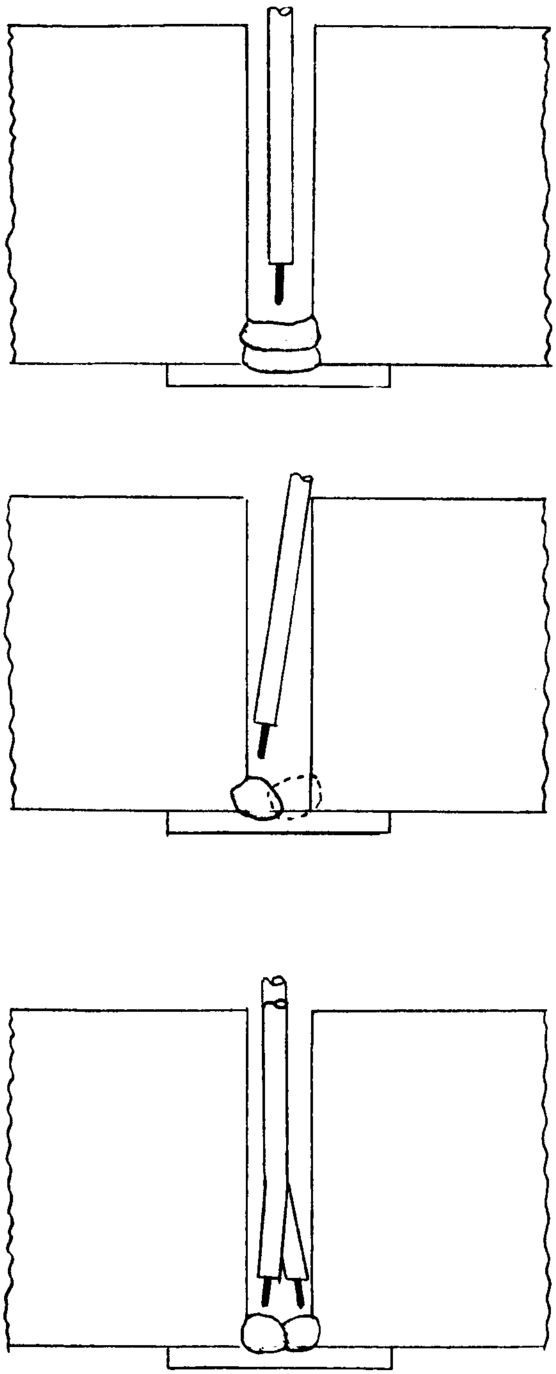
Shielding Studies

It was established that poor weld shielding was one of the major problems in Narrow-Gap welding of aluminum alloy plates in thicknesses of 2 inches and over. Considerable work was done during this program to develop better shielding nozzles. This development was done by building mock-ups of proposed nozzle configurations and passing a visible vapor through them to study the gas-flow pattern. Actual gas-shielding nozzles were then built and tested by the visible-vapor method and by actual use during welding. The nozzle mock-ups were made of thin aluminum sheet fastened together by tape. Experimental nozzles were made of welded copper sheet.

The visible vapor for flow-pattern studies was provided by bubbling mixtures of shielding gas through water, then passing this moisture-laden gas over liquid titanium tetrachloride.* The titanium tetrachloride reacts in the presence of the water vapor to form a dense, white vapor. This vapor was passed through the shielding nozzles.

The flow patterns of the nozzles and mock-ups were observed in a simulated Narrow-Gap joint made of Plexiglas. This joint is shown in Figure 8. The sidewalls of the joint and the plate surface were simulated by Plexiglas sheet as shown in the sketches at the bottom of Figure 8. The depth of the joint could be adjusted by inserting a strip of Plexiglas at the desired height in the joint. The joint gap was determined by the width of this strip. The flow pattern of the shielding-gas visible-vapor mixture could be observed through the transparent sidewalls of the simulated joint.

*Care should be exercised in using this technique to safeguard personnel and equipment against the HCl vapors produced.

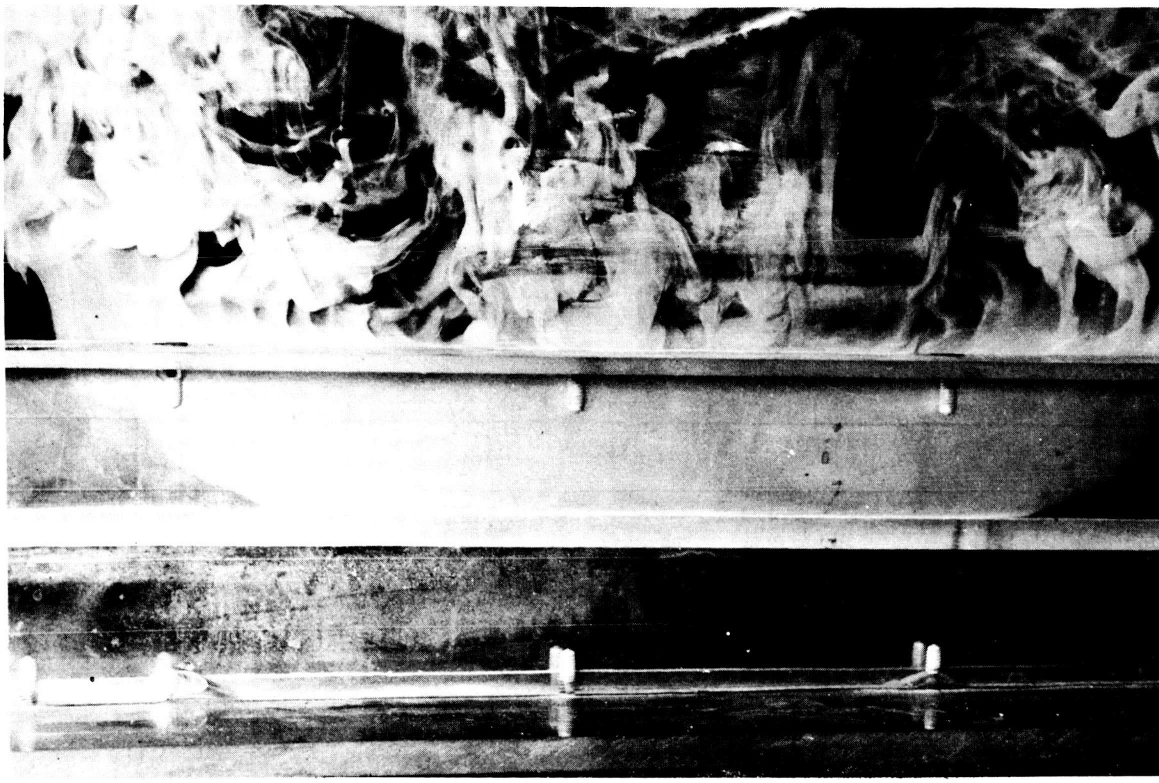


a. Single-Wire-Centered Technique

b. Single-Wire-Offset Technique

c. Twin-Wire Technique

FIGURE 7. CONTACT TUBE AND WIRE LOCATION FOR NARROW-GAP WELDING BY THE SINGLE-WIRE-CENTERED, SINGLE-WIRE-OFFSET, AND TWIN-WIRE TECHNIQUES



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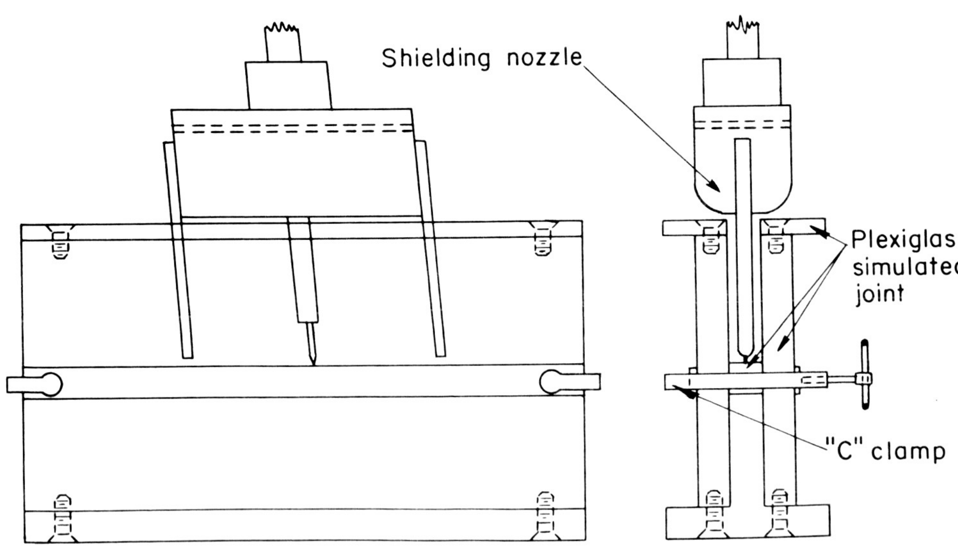
a. Visible-Vapor Shielding-Gas Study Being Conducted on Twin-Wire Shielding Nozzle



b. Sketch of Simulated Narrow-Gap Joint Used in Shielding Studies

FIGURE 8. SETUP USED TO EVALUATE SHIELDING-GAS NOZZLES USING VISIBLE VAPOR

Each nozzle or mock-up was tested over the simulated joint at varying flow rates. Shielding nozzles for single-wire welding were tested at flow rates varying from 20 to 80 cfh. Shielding nozzles for twin-wire welding were tested at flow rates varying from 30 to 160 cfh. The higher flow rates were 10 to 20 cfh above that required to obtain coverage of the visible vapor. The nozzle configurations were evaluated qualitatively by observing the flow of visible vapor from them during the test. The vapor acted as a tracer to indicate the path and the shielding pattern of the shielding gas. A dense vapor indicated good shielding coverage.

Nozzle configurations to be used for single-wire welding were tested in simulated joints having 1/4-inch-wide gaps, with a joint depth of 3 inches. Nozzle configurations to be used for twin-wire welding were tested in 1/2-inch-wide joints with a joint depth of 2-1/2 inches.

Nozzle configurations found acceptable on visible-vapor studies were then fabricated and used for welding. Flow rates at the high end of the range evaluated in the visible-vapor studies were used during welding. These flow rates were believed to be more than adequate to provide good gas coverage.

The visible-vapor studies indicated that these flow rates did not cause poor shielding due to turbulence. The effectiveness of the shielding nozzles was evaluated during welding by observing arc stability, appearance of the weld beads, and weld porosity.

Testing

Testing methods used to evaluate welding results included visual observation, radiographic examination, metallographic examination, hardness tests, tensile tests, and bend tests.

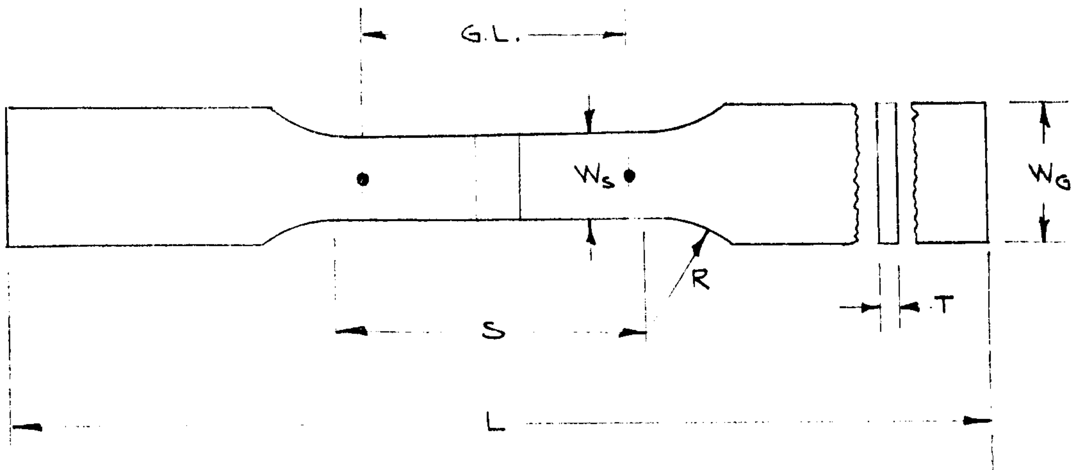
Visual observations were made of the arc during welding. The bead contour, the surface roughness and cleanliness of the weld beads were evaluated after each pass. Radiographs were taken to inspect for porosity, lack of fusion, or cracking. Radiographs were evaluated per MSFC-SPEC-259.

Metallographic cross sections of welds were prepared to examine the weld penetration and location, size, and extent of porosity, lack of fusion, or weld cracks.

The hardness of a number of weld macrosections was measured using a Rockwell Hardness Tester. Rockwell "B" measurements were made on the weld metal and the surrounding base metal. Hardness traverses of a twin-wire weld made with 300 F preheat and a similar twin-wire weld made without preheat were made with a Tukon hardness tester.

Transverse-weld specimens were taken from selected plates and tested in tension. The specimens were either standard 0.505 round specimens or standard rectangular specimens. A drawing of the rectangular specimen is shown in Figure 9.

Transverse-weld side-bend specimens were 1/8 inch thick and 1-1/2 inches wide. The specimens were bent around a series of dies, starting with a 3-inch-diameter die and progressing to smaller-diameter dies until the specimen cracked. The specimens were liquid dye checked after each bend to determine whether any cracks formed in the



G.L.	- Gage length	=	2.0
S	- Length of reduced section	=	3.0
W_S	- Width of reduced section	=	1.0
T	- Specimen thickness	=	.625
L	- Overall length	=	10.0
R	- Radius	=	2.0
W_G	- Width of grip ends	=	1.5

Note: Ends shall be symmetrical within 0.01 in.

FIGURE 9. RECTANGULAR TENSION TEST SPECIMEN

weld zone. The total percent elongation was calculated from the minimum radius used prior to the bend which caused cracking. The elongation was calculated from the formula:

$$\text{Elongation}^{*}, \text{ percent} = \frac{T(100)}{2R + T} \quad ,$$

where T = thickness of the specimen

R = minimum radius of bend prior to failure.

DISCUSSION OF SPECIAL EQUIPMENT COMPONENTS

Several changes were made to the basic commercial gas-shielded metal arc-welding equipment. A number of contact tube and gas-shielding nozzle designs were evaluated. Changes were made to the wire-guide system to support the welding wire and control wire cast at the arc. These changes are described below.

Special Contact Tubes

In commercial gas-shielded metal-arc welding equipment the wire electrode is guided through the torch in a copper or copper-alloy contact tube. Contact tubes for the Airco Model 60A welding barrels used in this program are normally 1/4 inch OD and have an ID slightly greater than the wire diameter. The functions of the contact tube are: (1) to guide the wire to the weld puddle, and (2) to transfer welding current to the wire. The contact-tip-to-work distance should be as short as possible (within proper welding operating characteristics) to provide maximum guidance of the wire and prevent overheating of the wire due to the current flowing through it.

In normal gas-shielded metal-arc welding the contact tips are kept within or protrude slightly below the shielding-gas nozzle. In Narrow-Gap welding, the contact tubes are inserted into the narrow welding groove and therefore protrude 1 inch or more from the shielding nozzle depending on the thickness of the plate being welded.

Theoretically, a bare contact tube can be used for Narrow-Gap welding as long as it does not touch the work. If the contact tube shorts out to the work during welding, the tube is melted and destroyed before the equipment can be shut off. More serious than the loss of the contact tube is the contamination of the work with copper.

There is another way, however, in which the weld can become contaminated with copper. This is the so-called "burnback" which is common in both standard gas-shielded metal-arc and Narrow-Gap welding. In either type of gas-metal-arc welding, an arc must be initiated by touching the electrode to the work, the air and shielding-gas mixtures being good insulators. Once the arc is initiated, however, the ionized gases in the arc provide a ready path for the welding current. As long as the equipment operates properly, the highly directional arc which is characteristic of the gas-metal-arc process

*This formula is based on the assumption that neutral axis of the bend-test specimen is at the mid-thickness of the specimen. The values computed using this formula are a good approximation of the ductility exhibited in the bend test.

will stay at the end of the consumable wire and be directed to the root of the joint. If there is a momentary stoppage in wire feeding, or if in Narrow-Gap welding the wire is inadvertently moved too close to the sidewall during welding, the arc moves up the wire arcing to the joint sidewall and melts the end of the contact tube, causing copper contamination in the weld.

Copper contamination in standard gas-shielded metal-arc welding, therefore, is most likely to occur due to burnbacks caused by a momentary delay in wire feed. Additional causes of copper contamination are present in Narrow-Gap welding. Since the contact tube is inserted into the joint, copper contamination can also occur (1) due to shorting-out of the contact tube to the joint sidewall, and (2) due to burnback caused by the arc traveling up the wire and melting the end of the contact tube. The contact tubes for Narrow-Gap welding are therefore usually insulated to prevent shorting-out and, as will be pointed out later, to prevent copper contamination if burnback occurs.

Contact Tube Configurations

Sketches of the contact tube configurations evaluated during this program are shown in Figure 10.

Contact Tube A is a commercially available contact tube. The end of the tube is machined to 1/8-inch diameter for a length of approximately 3-1/2 inches to provide adequate operating clearance in the narrow groove joint. This type of contact tube operates satisfactorily except it has no protection against shorting-out to the joint sidewall. Also, in the event of wire burnback the weld may become contaminated with copper.

The operating temperature of this contact tube was measured using a chromel-alumel thermocouple attached to the tube 1/4 inch above the tip. Three welding passes were made during this test, and temperature readings were recorded during each pass using a Brown recording meter. The welding conditions used were 210-220 amperes, 25 volts, and 35 seconds total weld time. The contact tube quickly reached an operating temperature of 350 to 360 F (within approximately 5 seconds) and remained constant for the remainder of a 35-second operating time. The contact tip cooled to room temperature rapidly after welding was stopped.

Several contact tubes were made with a plasma sprayed coating of zirconia or titania on the ends to insulate the tube from the joint sidewall. The lower end of these tubes was rectangular in section as shown in Figure 10. It was found that the sprayed coatings were unsatisfactory. They tended to spall during welding due to differential expansion of the copper tube and the coating. Also, the coatings were extremely fragile and chipped off very easily.

The end of the Type C contact tube shown in Figure 10 was bent to direct the wire against the joint sidewall. This was done to permit welding with the contact tube spaced further away from the joint sidewall. The contact tube body was not insulated. Some welds were made with a nylon guide attached near the tip of the tube to prevent shorting-out to the sidewall. The Type C contact tubes were effective in preventing shorting-out to the joint sidewall; however, they could still cause copper contamination if burnbacks occurred.

The Type D contact tubes were the most effective used during this program. These contact tubes are similar to Type A, except they were insulated with a mullite ceramic

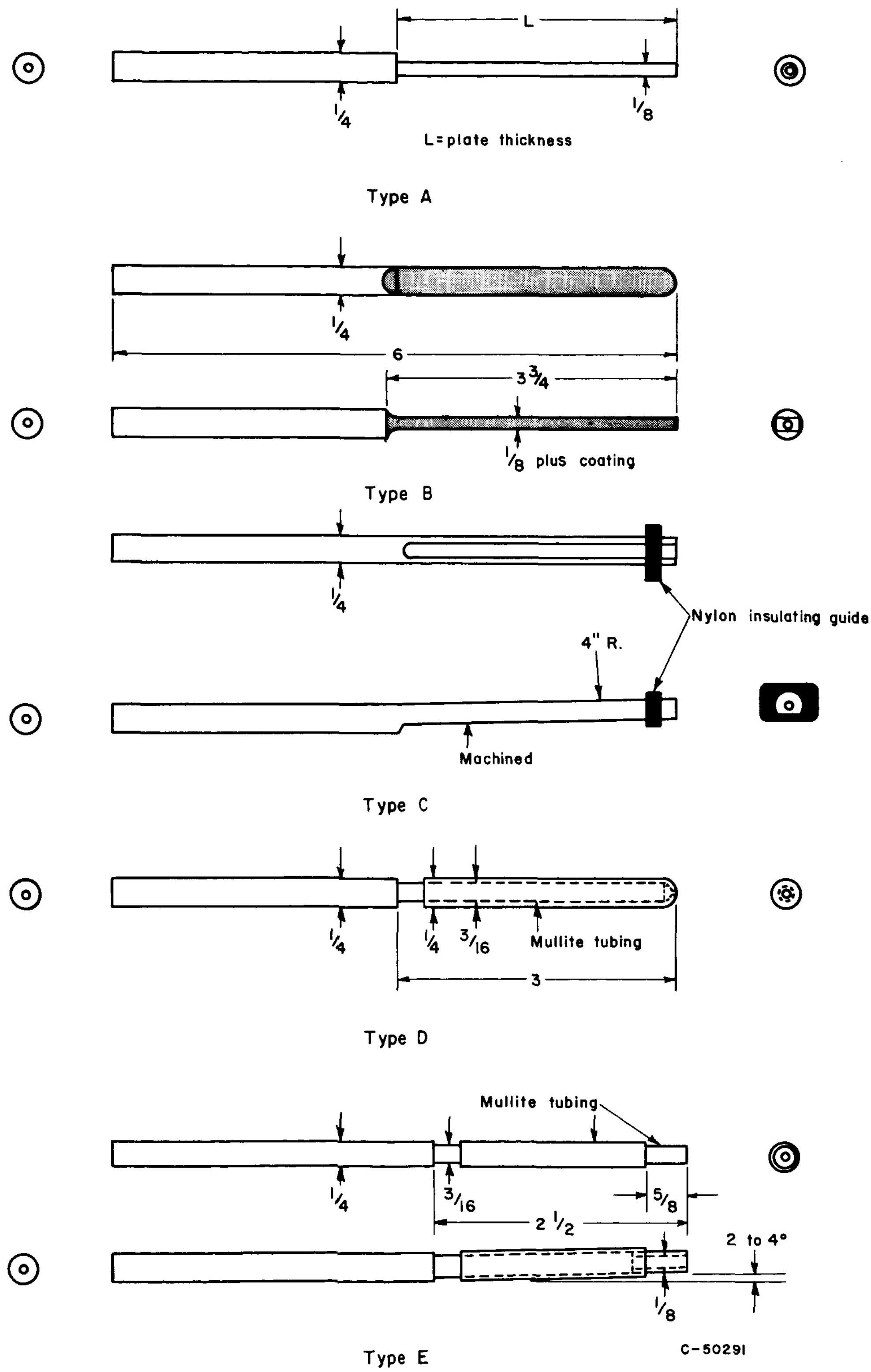


FIGURE 10. SKETCHES OF CONTACT TUBES EVALUATED FOR NARROW-GAP WELDING THICK GAGE 2219-T31 ALUMINUM

tube. The mullite tube was closed at one end. A hole was drilled in the closed end to permit passage of the welding wire. The insulation then covered the end of the contact tube as well as the side. In the event of a burnback the wire melted back to the mullite but did not melt the copper tube or cause contamination of the weld. The Type D contact tube was very effective when used with the single-wire-centered welding technique.

In twin-wire welding, it is necessary to use a contact tube with a smaller diameter at the end than in the Type D contact tube so that the wire could be positioned near the sidewall. Contact Tube Type E was most effective for twin-wire welding. The end of the contact tube was bent to direct the wire toward the side of the joint. The diameter at the end of the contact tube was smaller than that of Contact Tube D so that the contact tube could be placed closer to the side of the joint. Mullite tubing was used to insulate the contact tube. Since mullite tubes with capped ends were not readily available, the end of the contact tube could not be insulated. It is believed, however, that mullite tubes having a capped end could be obtained in the smaller diameter size. It is recommended that these be used as in the Type D contact tube to effectively eliminate danger of contamination in the Narrow-Gap welds.

Shielding Nozzles

During this program, it was necessary to develop special shielding nozzles for Narrow-Gap welding. Standard commercial 3/4-inch-diameter nozzles shown in Figure 11 provided good shielding when depositing Narrow-Gap welds in 1-inch-thick aluminum alloy plates. A number of welds were also made in 2-inch-thick plate using standard shielding nozzles. When the first attempts were made to weld 3-inch-thick aluminum alloy plate, it became apparent that improved shielding was required. Weld beads made in 3-inch aluminum plate using the commercial 3/4-inch-diameter nozzle had an irregular and dirty surface, and the arc was very erratic and unstable. It appeared that the shielding gas was not flowing to the bottom of the 3-inch-deep gap.

A 3-inch-thick plate was then welded inside an enclosure to see whether the thicker plate could be welded with improved shielding. The enclosure was built to surround the 18-inch-long weld joint. The enclosure was 8 inches wide and about 6 inches deep. The nozzle of the welding barrel projected through a loosely fitting sliding Plexiglas top. The enclosure was purged by introducing the He-A shielding-gas mixture through the nozzle for 15 to 20 minutes before each pass. During welding, the weld joint was shielded by the shielding-gas atmosphere inside the enclosure as well as by shielding gas flowing through the nozzle. The welding arc was much more stable, and the appearance of the bead surface was greatly improved over welds attempted in 3-inch plate without the enclosure. It was recognized, however, that this type of shielding is costly and severely limits accessibility. The visible-vapor shielding-gas studies described previously were therefore begun to develop an improved shielding nozzle for Narrow-Gap welding thick aluminum.

Shielding Setup A shown in Figure 12 conducted shielding gas into the bottom of the joint by auxiliary tubing. These auxiliary shielding devices were used in conjunction with the standard torch nozzle. This shielding method was unsatisfactory due to turbulence and air being drawn into the weld area. Shielding Setup B shown in Figure 13 was also unsatisfactory because of lack of adequate gas coverage.

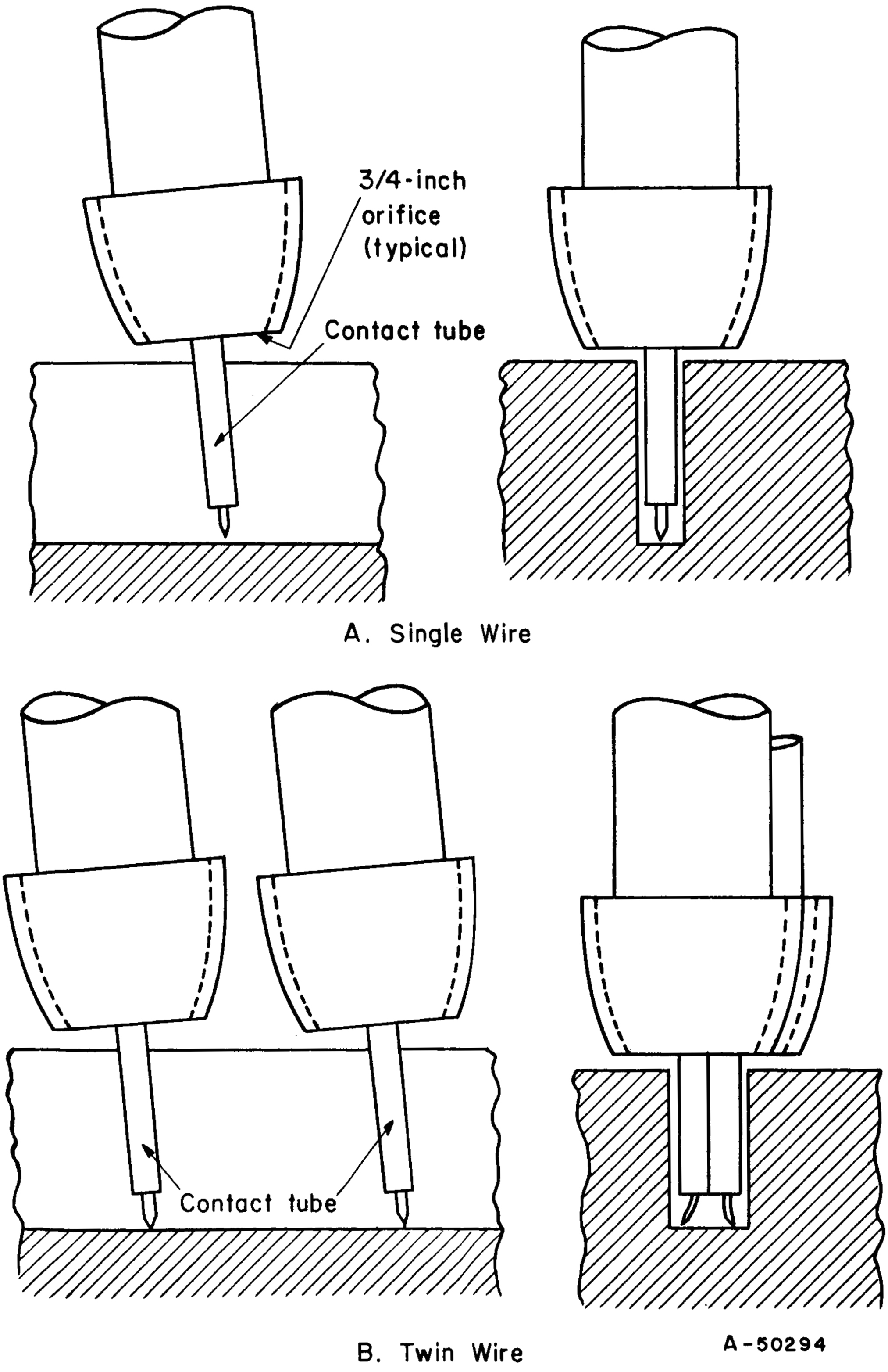


FIGURE 11. COMMERCIAL 1-INCH-DIAMETER SHIELDING NOZZLES SET UP FOR SINGLE-WIRE AND TWIN-WIRE WELDING

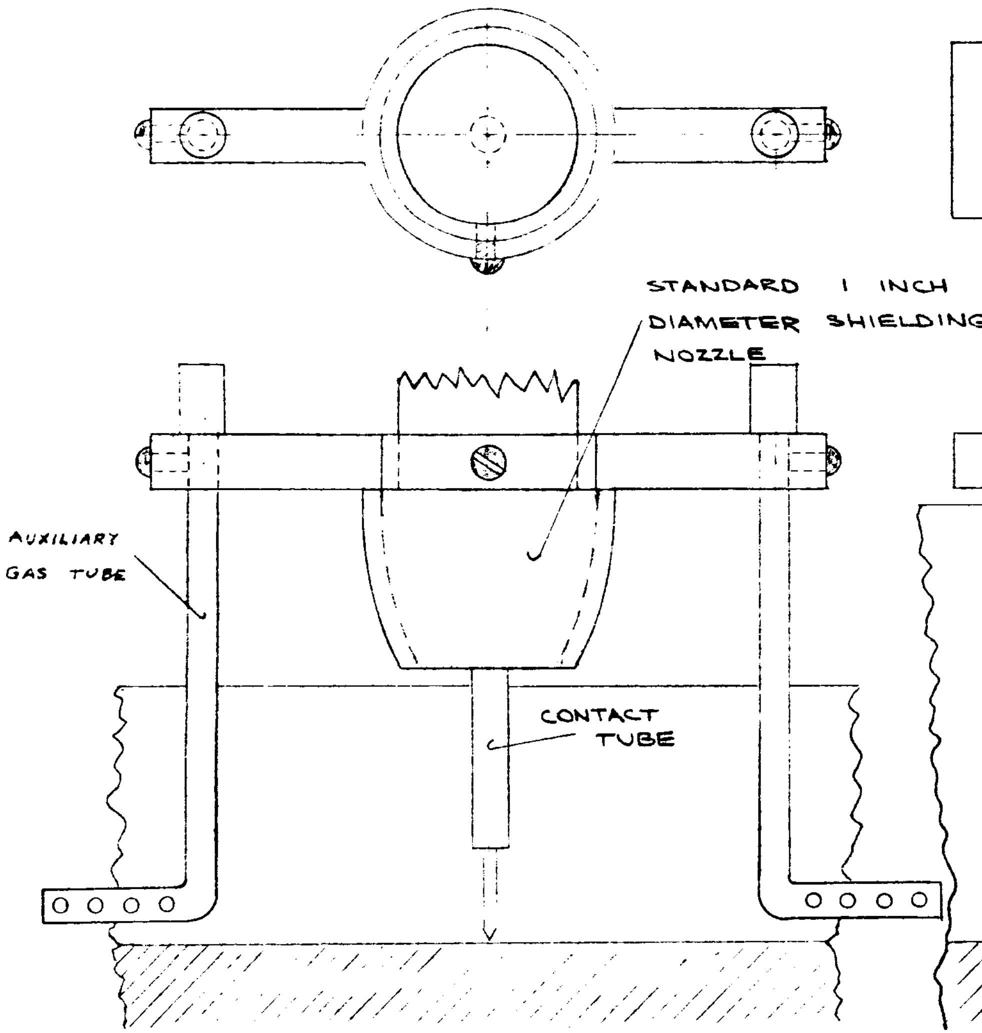


FIGURE 12. EXPERIMENTAL SHIELDING SETUP A

Standard shielding nozzle with auxiliary gas feed tubes in the joint

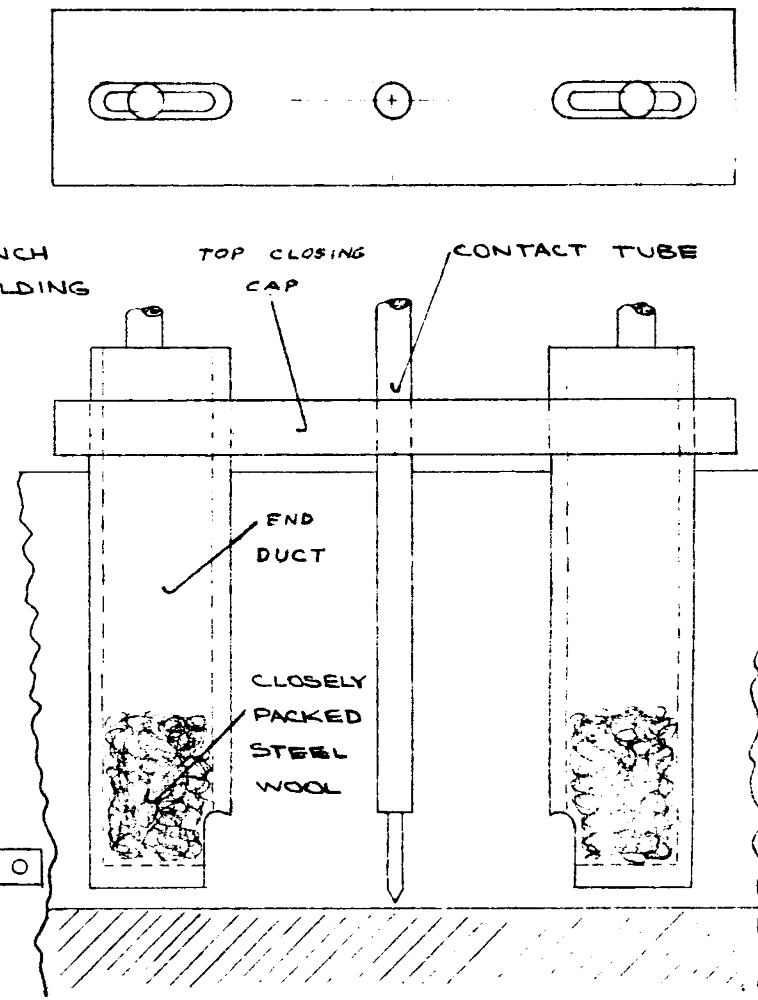


FIGURE 13. EXPERIMENTAL SHIELDING SETUP B

End ducts carry shielding gas to the bottom of the joint.

The shielding methods that seemed to work best were those that contained the shielding gas and restricted its escape so that a pressure slightly above the ambient pressure was built up around the arc. This evidently kept air from being drawn into the arc. Type C shielding nozzle (see Figure 14), a duct projecting into joint, was used successfully to make a number of welds in joints 2-1/2 inches deep. The end tabs on this shield were placed close to the bottom of the joint during welding. The escape of the gas was thus restricted and the resulting pressure buildup of shielding gas eliminated air. A disadvantage of this type of shield, however, was the fact that it sometimes caught on the sides of the joint, especially if joint shrinkage occurred. This resulted in irregularity or stoppage of travel.

A nozzle built to the configurations shown in Figures 15 and 16 proved to be the most satisfactory of the various shielding setups evaluated. These nozzles provided good shielding and avoided the problems inherent in the other types of shielding setups where inflexible parts of the shield projected into the narrow groove. Tests of these nozzles by the visible-vapor method indicated that the flexible Teflon end baffles and the skirt used on the twin-wire nozzle guided the shielding gas into the joint, restricting its escape until it reached the bottom of the joint. There was no indication that air was being aspirated into the arc.

Wire-Guide Tube Modification

One of the difficulties encountered in this program was that of feeding fine aluminum wire with the standard commercial wire-feed systems. The column strength of the wire is low, and even a slight resistance or drag at the contact tube end of the wire caused it to buckle and become tangled, stopping the wire feed. The wire usually buckled between the exit of the drive rolls and the entrance to the wire guide. At times, however, the wire buckled in the flexible nylon liner between the feed rolls and the contact tube.

The commercial wire-feed system that was used in this program had a nylon liner between the drive rolls and the contact tube. The inside diameter of the welding barrel surrounding the liner was much larger than the outside diameter of the flexible nylon liner. When the wire stubbed into the work, either at the weld start or momentarily during welding, the wire and the nylon liner were free to bend. It was then difficult to feed the bent wire through the contact tube. The occurrence of stubbing is probably more frequent during Narrow-Gap welding than in normal gas-shielded metal-arc welding, since the Narrow-Gap process uses a very short arc length in the spray-transfer range.

The guide-tube systems of the welding heads were modified to fully support the wire as it exited from the drive rolls and passed through the nylon liner to the contact tube (see Figure 17). A wedge-like wire guide was contoured to fit very closely to the wire-feed rolls so that the wire was supported as it exited from the rolls. The nylon tubing that extended from the wire guide to the contact tube was fully supported by a length of steel tubing. One end of the nylon liner was placed in a counterbored recess in the end of the contact tube.

The wire-guide tube modification was effective in reducing the number of wire stoppages. Tests of the wire-guide system were made in which the wire was deliberately stubbed into the plate at normal contact-tube-to-work distance with no welding current applied. After the modifications were made, the wire bent upon striking the plate but continued to feed.

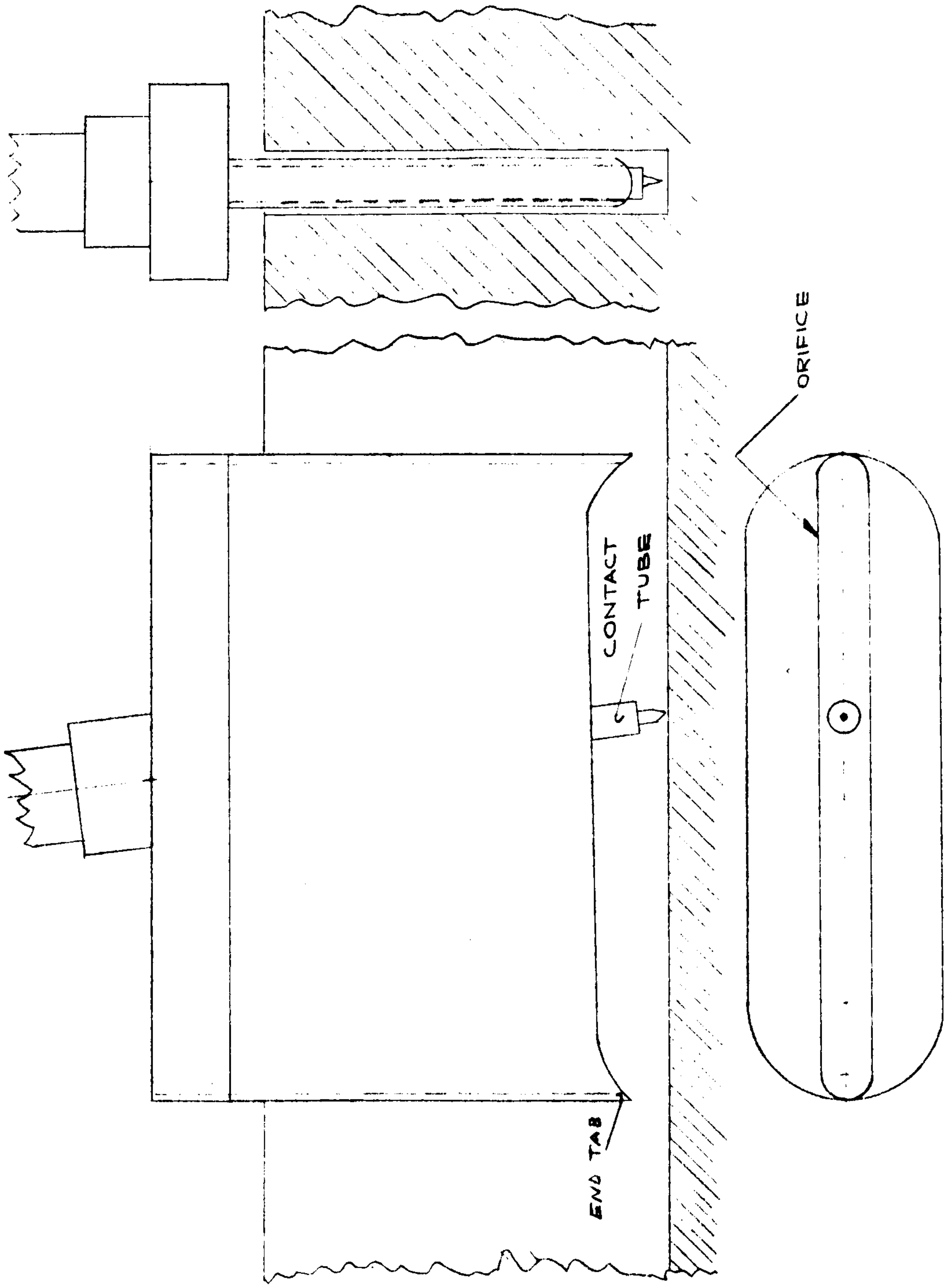


FIGURE 14. EXPERIMENTAL SHIELDING NOZZLE C

Nozzle extends into narrow-groove joint.

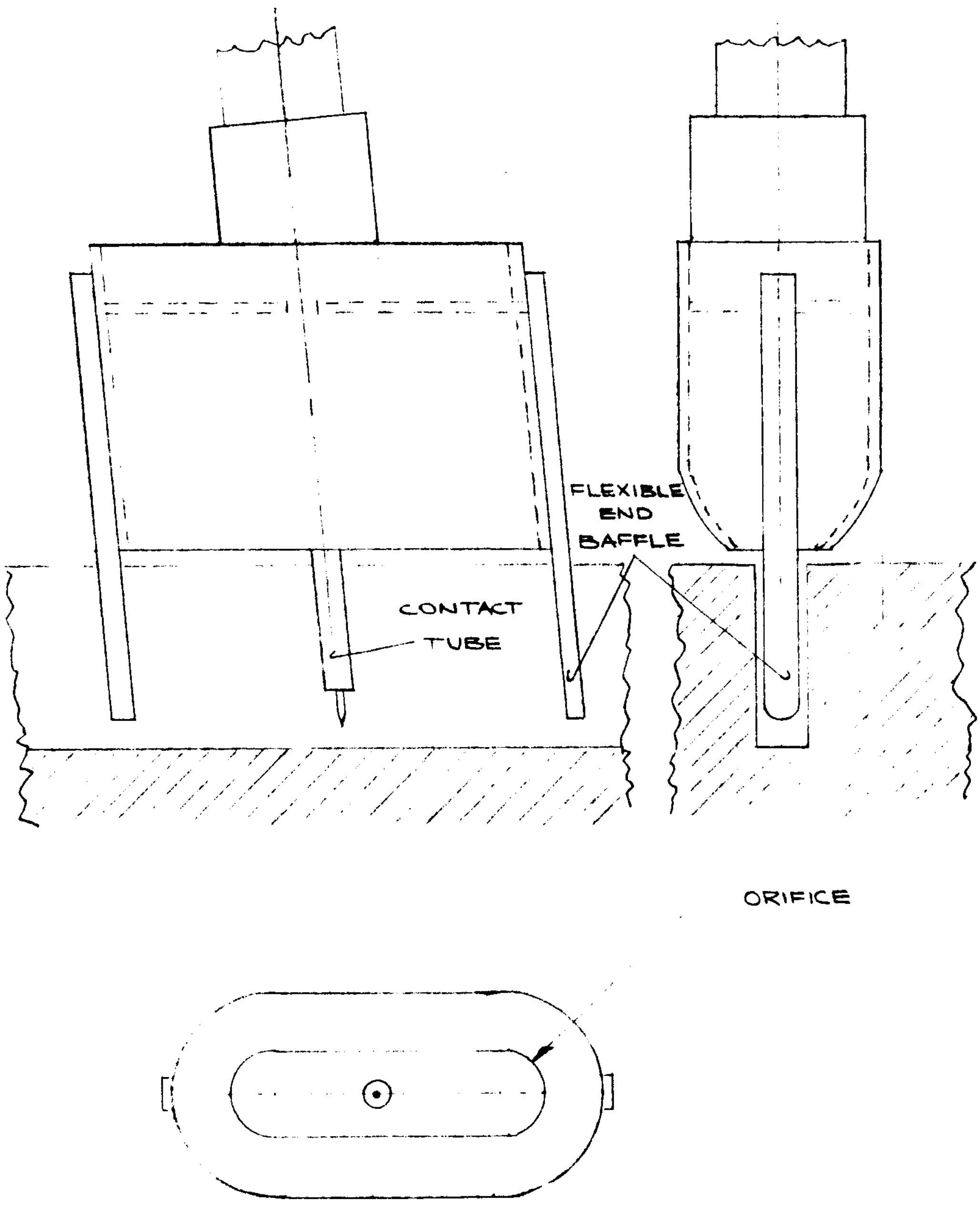


FIGURE 15. EXPERIMENTAL SHIELDING NOZZLE D

Elongated nozzle with end baffles which extend into narrow-groove joint.

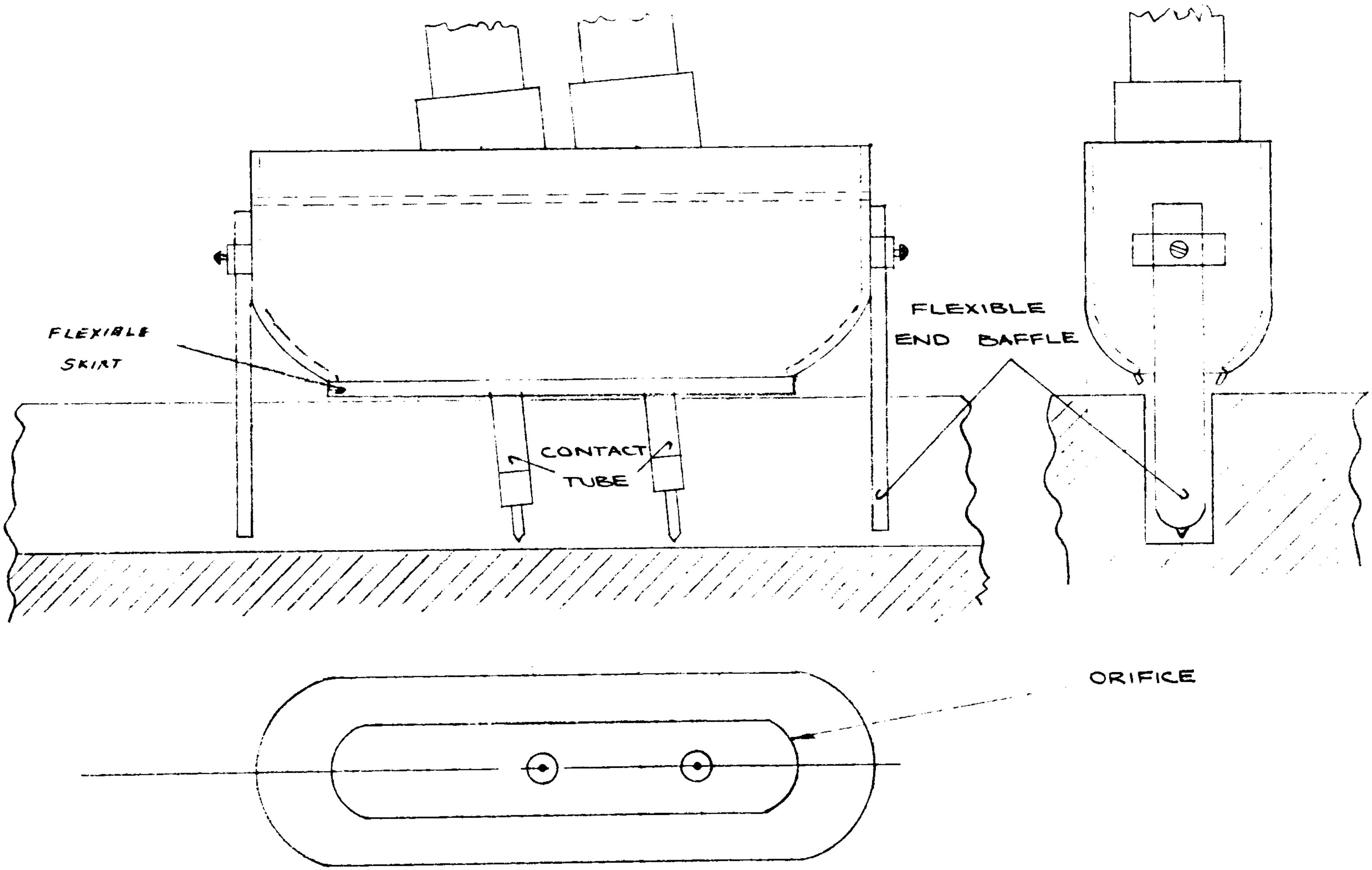
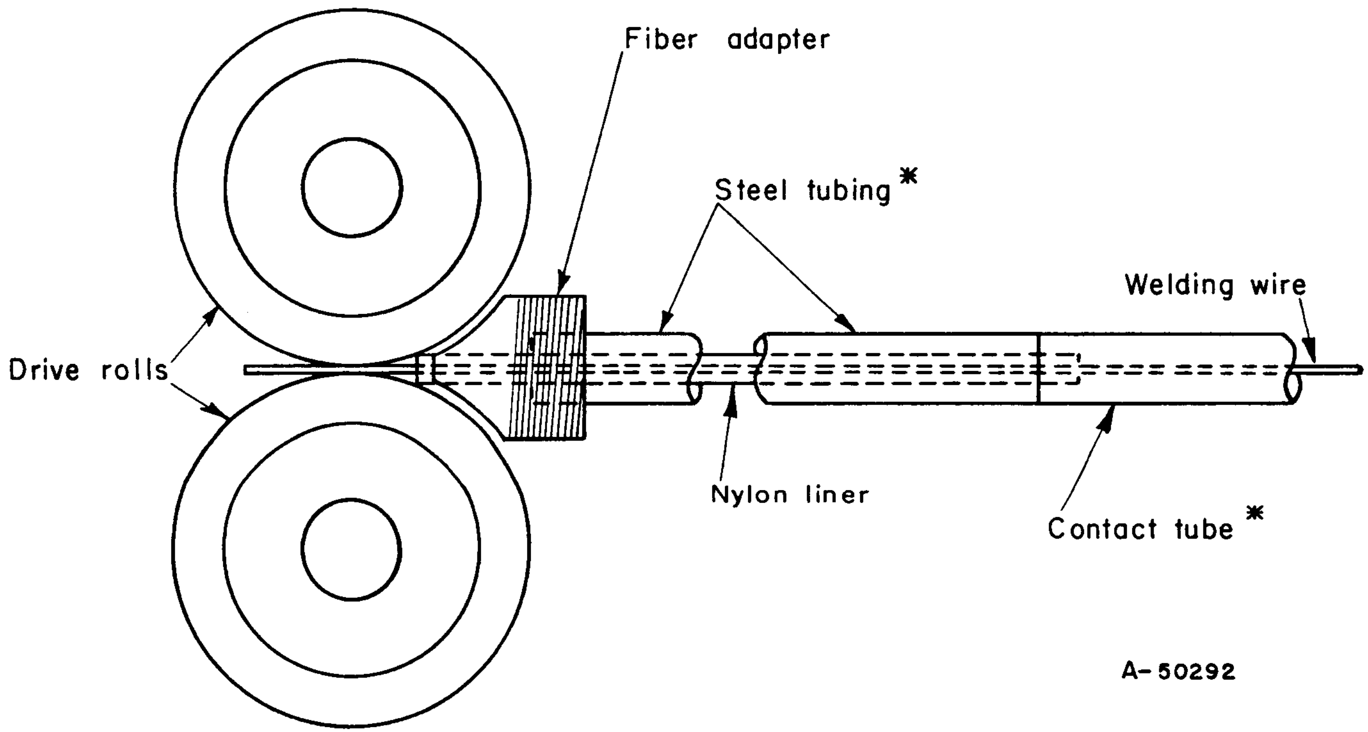


FIGURE 16. EXPERIMENTAL SHIELDING NOZZLE E

Elongated nozzle for twin-wire welding similar to Type D in Figure 15.



* The steel tube and a portion of the contact tube are enclosed in a water-cooled cylinder.

FIGURE 17. MODIFICATION OF WIRE-GUIDE TUBE FOR SUPPORTING AND GUIDING FINE ALUMINUM WIRE

Modification to Control Wire Cast

A device was added to the wire-feed equipment to control wire cast during twin-wire welding. It was found that the fillet-type weld beads required for twin-wire welding have a much better sidewall penetration and a better contour if the filler wire is angled toward the sidewall. This can be done to some extent by bending and angling the contact tubes toward the sidewalls. Directing the wire by bending the contact tube is limited, however, because of the confinement of the narrow joint. It is also difficult to feed wire through a bent contact tube.

Figure 18 shows the controlled wire-cast system used on each of the welding heads during twin-wire studies.* This setup caused the wire to be bent around one of the wire-drive rolls, entering the wire-feed rolls in a direction perpendicular to the contact tube. Bending the wire over one of the rolls puts a controlled cast in it. The direction of the cast is controlled so that the wire is directed toward the side of the joint as it exits from the contact tube.

The modification to control wire cast during twin-wire welding was rather effective in keeping the magnitude and direction of the wire cast constant. Figure 19 shows the cast formed on a cold 3/64-inch-diameter aluminum wire. The radius of this cast is approximately 6-1/2 inches. Figure 20 illustrates the improvement in weld quality resulting from use of controlled wire cast.

The cast in the aluminum wire was not in itself enough to properly angle the filler wire toward the sidewalls. It was therefore necessary to bend the contact tube slightly to help accomplish this positioning. Perhaps an aluminum filler wire cold worked to a higher strength level would maintain a smaller diameter cast so that it would not be necessary to bend the contact tubes. This controlled cast system was used very effectively in other welding studies with steel wire. The steel wire maintained a cast radius of approximately 3 inches which was sufficient to assure adequate sidewall penetration even under adverse operating conditions.

*This method of controlling the cast of a welding wire is believed to be patentable. The idea was conceived and reduced to practice on another Battelle project conducted for the U.S. Navy, Bureau of Ships. Battelle will elect to take title to this invention as provided for in our contract with the Bureau of Ships. Under the terms of this contract, the U. S. Government will receive a royalty-free license to practice the invention for Government purposes.

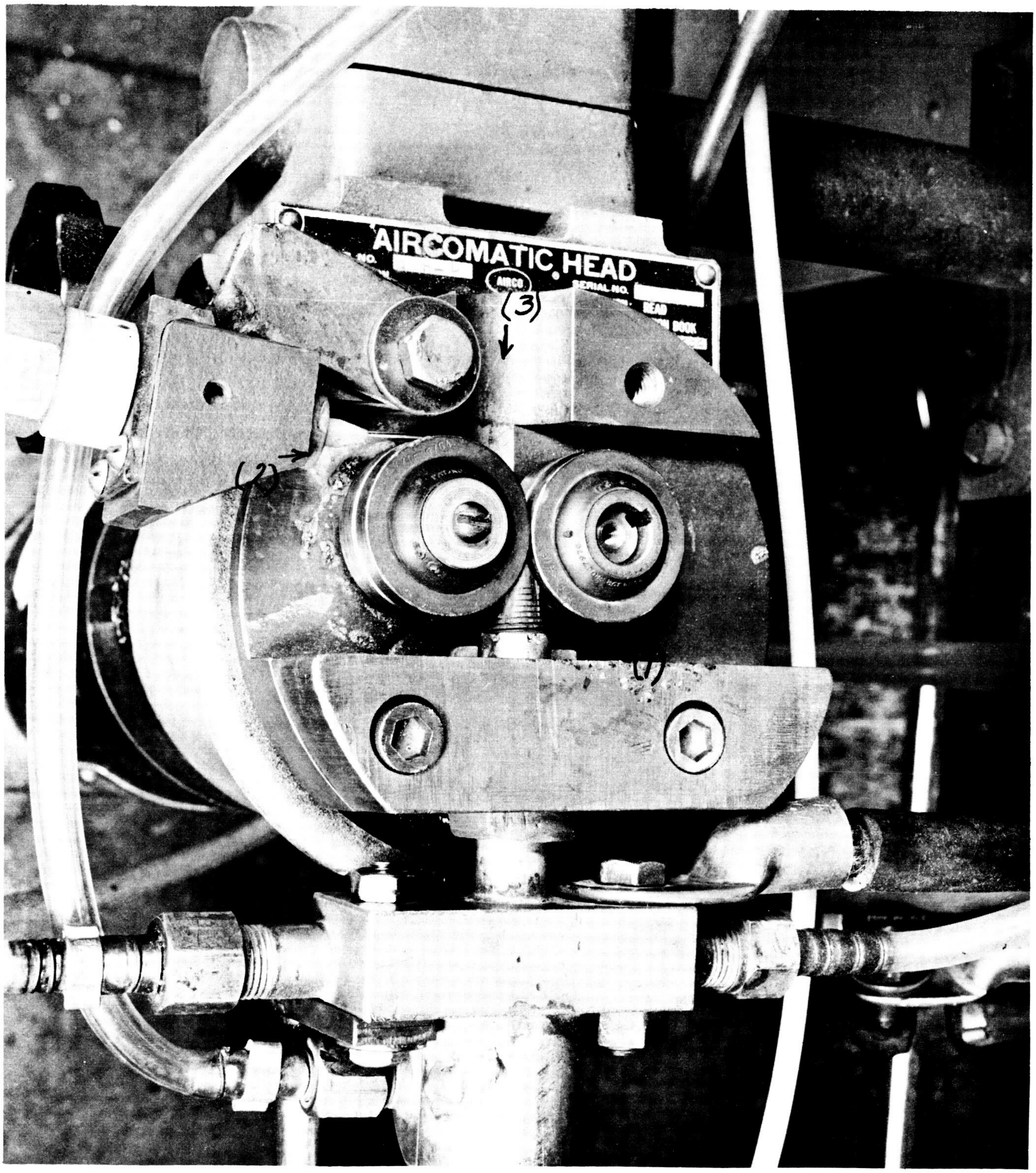


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FIGURE 18. MODIFICATIONS MADE TO WELDING HEAD TO IMPROVE WIRE SUPPORT AND OBTAIN CONTROLLED WIRE CAST

A chamfered wire guide (1) is closely fitted against the exit side of the drive rolls to support the wire. The wire feeds into the drive rolls in a direction (2) 90 degrees to normal wire feed direction (3). The wire is bent around one of the rolls thus producing a controlled cast in the wire.

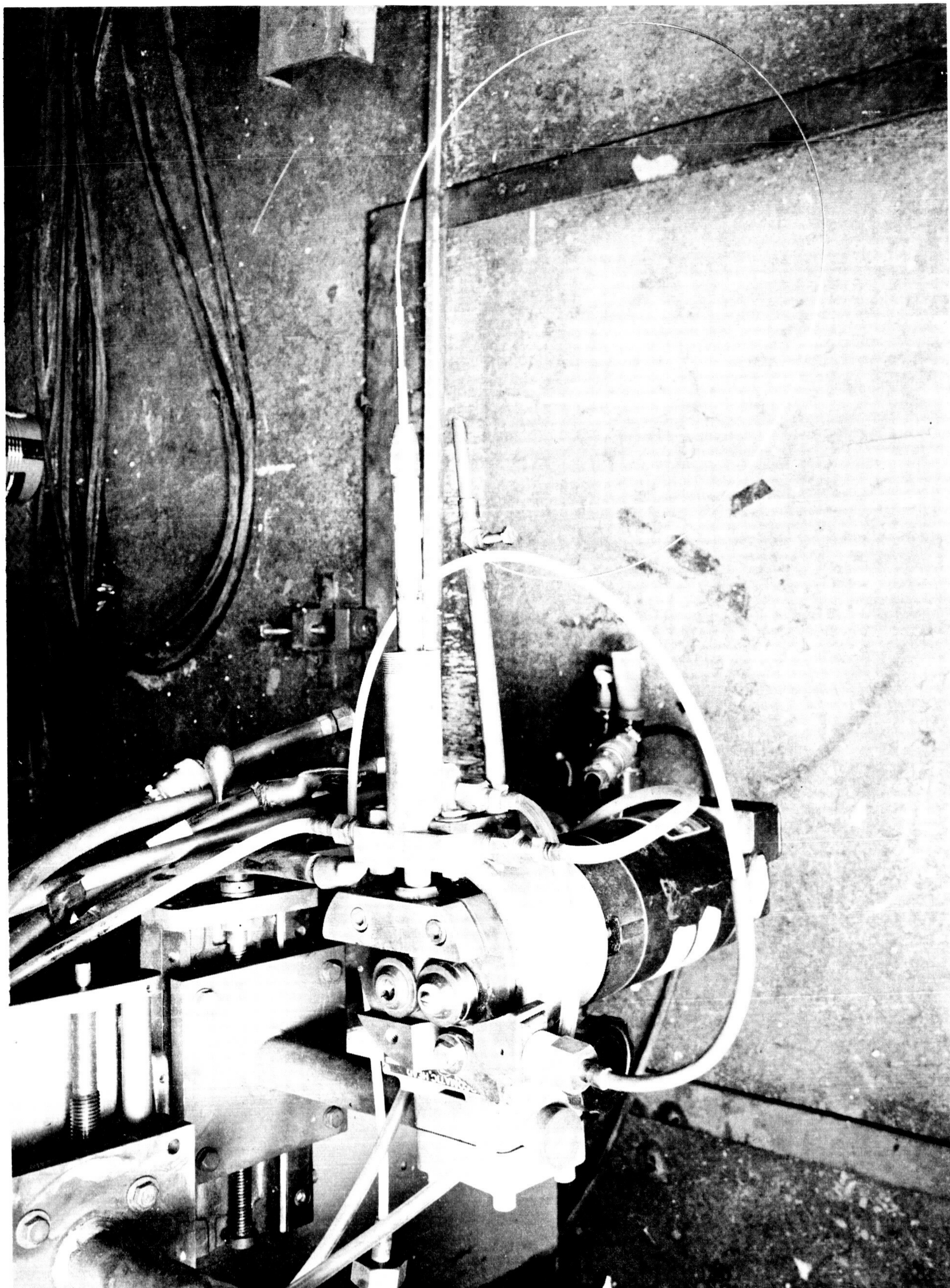

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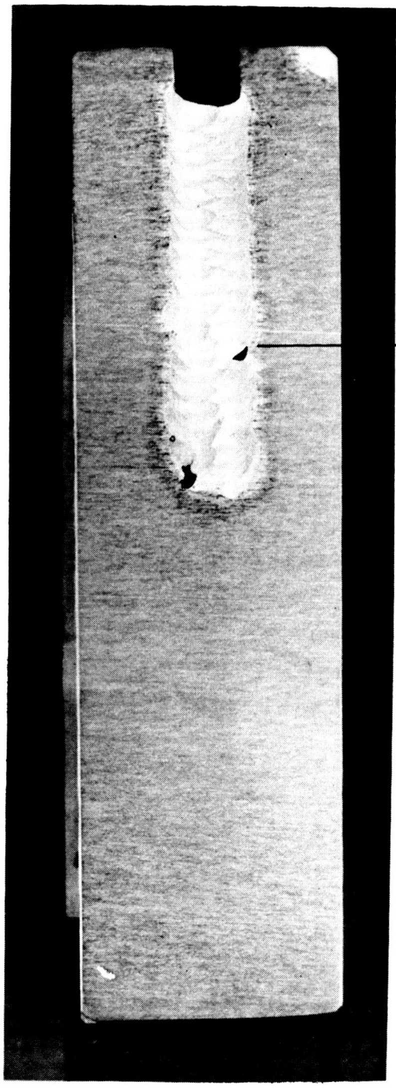
FIGURE 19. CONTROLLED CAST IN 3/64-INCH-DIAMETER 2319 ALUMINUM ALLOY WIRE



Cast system used above this point, not used below

16089

FIGURE 20. MACROSECTION SHOWING EFFECT OF USING CONTROLLED-WIRE CAST DURING WELDING

RECOMMENDED NARROW-GAP WELDING PROCEDURES

Procedures were developed for Narrow-Gap welding thick-gage 2219-T31 aluminum using the single-wire-centered technique in the flat and horizontal positions and the twin-wire technique in the flat and vertical positions. Recommended procedures for flat-, vertical-, and horizontal-position welding are given in Tables 1-3. These procedures were not tested in the full 1 to 5-inch-thickness ranges. Based on the results of numerous test welds made during the program, however, applicable plate thicknesses have been assigned to each procedure as listed in Tables 1-3.

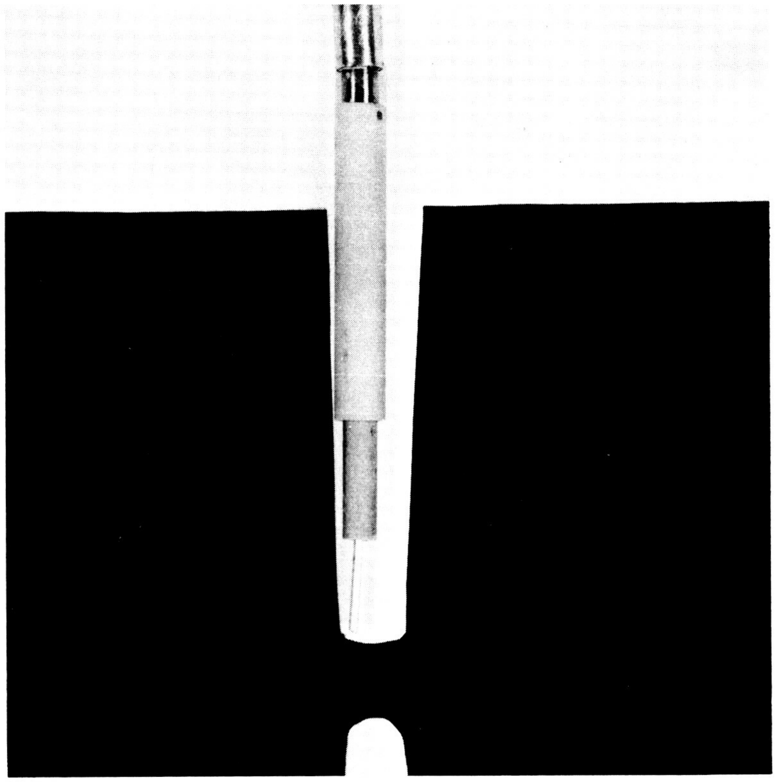
The radiographic quality of the Narrow-Gap welds made using the recommended procedures were Grade 2 or better, according to MSFC-SPEC-259.

The transverse weld tensile strength of the Narrow-Gap welds 2219-T31 plate tested as welded ranges from 40 to 42 ksi with elongations in 2 inches of 4 to 6 percent. The weld-metal elongation as measured in transverse side bend tests is approximately 10 percent with specimens conforming to a minimum die radius of 1/2 inch without fracturing.

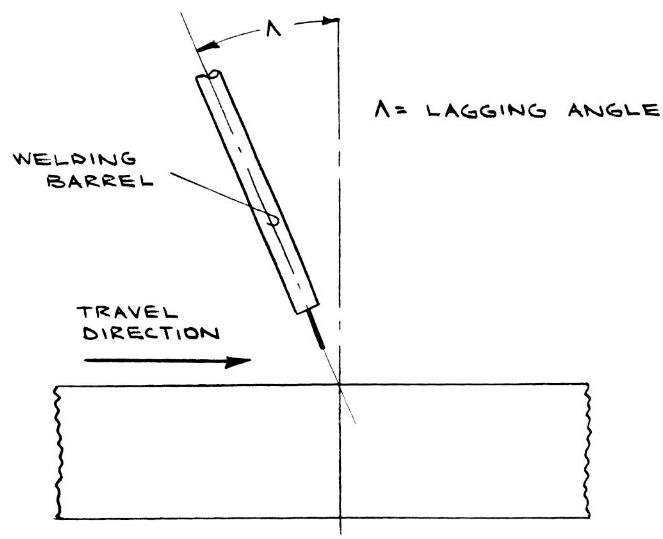
TABLE 1. RECOMMENDED PROCEDURES FOR NARROW-GAP WELDING THICK-GAGE 2219-T31 ALUMINUM ALLOY PLATES IN THE FLAT POSITION

Welding Technique	Single-Wire-Centered	Twin-Wire
Plate thickness, inch	1 to 2	1 to 5
Joint gap, inch	1/4	3/8
Filler wire		
Type	2319	2319
Diameter	3/64	3/64
Position in groove(a)	Center	1/16" from joint edge
Shielding gas		
Percentage composition	65He-35A	65He-35A
Total flow rate, cfh	50 to 80	50 to 120
Contact tube		
CTWD,(b) inch	1/2	1/2
Separation,(c) inch	--	1-1/4
Travel speed, ipm	25	37
Lead wire		
Feed rate, ipm	Approx 370	Approx 340
Cast, inch diameter(d)	None	13
Arc volts, DCRP	23 to 25	21
Current, amp	210 to 230	180 to 190
Trail wire		
Feed rate, ipm	--	Approx 340
Cast, inch diameter(d)	--	13
Arc volts, DCRP(e)	--	21
Current, amp	--	185 to 190
Shielding nozzle(f)	Type D	Type E
Head angle(g)	7 deg lagging	7 deg lagging

(a) Wire position in the weld joint is measured from the sidewall to the wire centerline, measurement being made at the bottom of the joint with the wire extended to the work. See Figure 21.
(b) CTWD - Contact-Tube-to-Work Distance.
(c) Separation - Distance between the two contact tubes measured along the centerline of the joint.
(d) Cast - Free diameter of filler wire after it leaves the contact tubes.
(e) DCRP - Direct Current Reverse Polarity.
(f) Shielding-nozzle types are shown in Figures 15 and 16.
(g) Sketch showing the head angle is contained in Figure 21b.



a. Contact Tube in Position for Twin-Wire Welding



b. Sketch Illustrating Head Angle

FIGURE 21. POSITION OF CONTACT TUBE AND WELDING TORCH

TABLE 2. RECOMMENDED PROCEDURE FOR NARROW-GAP WELDING THICK-GAGE 2219-T31 ALUMINUM ALLOY PLATES IN THE VERTICAL POSITION

Welding Technique	Twin-Wire
Plate thickness, inch	1 to 5
Joint gap, inch	3/8
Filler wire	
Type	2319
Diameter	3/64
Position in groove[a]	1/16" from joint edge
Shielding gas	
Percentage composition	65He-35A
Flow rate	50 to 120
Contact tube	
CTWD[b], inch	1/2
Separation[c], inch	1-1/4
Travel speed, ipm	40 to 42
Lead wire	
Feed rate, ipm	Approx 340
Cast[d], inch diameter	13
Arc volts[e], DCRP	21.5
Current, amp	190
Trail wire	
Feed rate, ipm	Approx 335
Cast, inch diameter	13
Arc volt, DCRP	20
Current, amp	180
Shielding nozzle[f]	Type E
Head angle[g]	7 deg lagging

(a) Wire position in the weld joint is measured from the sidewall to the wire centerline, measurement being made at the bottom of the joint with the wire extended to the work. See Figure 21.

(b) CTWD - Contact-Tube-to-Work Distance.

(c) Separation - Distance between the two contact tubes measured along the centerline of the joint.

(d) Cast - Free diameter of filler wire after it leaves the contact tubes.

(e) DCRP - Direct Current Reverse Polarity.

(f) Shielding-nozzle Type E is shown in Figure 16.

(g) Sketch showing the head angle is contained in Figure 21b.

TABLE 3. RECOMMENDED PROCEDURE OF NARROW-GAP WELDING THICK-GAGE 2219-T31 ALUMINUM ALLOY PLATES IN THE HORIZONTAL POSITION

Welding Technique	Single-Wire-Centered
Plate thickness, inch	1 to 2
Joint gap, inch	1/4
Filler wire	
Type	2319
Diameter, inch	3/64
Position in groove[(a)]	Center
Shielding gas	
Percentage composition	65He-35A
Flow rate, cfh	50
CTWD[(b)], inch	1/2
Travel speed, ipm	25
Wire feed speed, ipm	Approx 390
Arc volts, CDRP[(c)]	23 to 24
Current, amp	210 to 230
Shielding nozzle[(d)]	Type 6
Head angle[(e)]	7 deg lagging

(a) Wire position in the weld joint is measured from the sidewall to the wire centerline, measurement being made at the bottom of the joint with the wire extended to the work. See Figure 21.
(b) CTWD - Contact-Tube-to-Work Distance.
(c) DCRP - Direct Current Reverse Polarity.
(d) Shielding nozzle Type D as shown in Figure 15.
(e) Sketch showing the head angle is contained in Figure 21b.

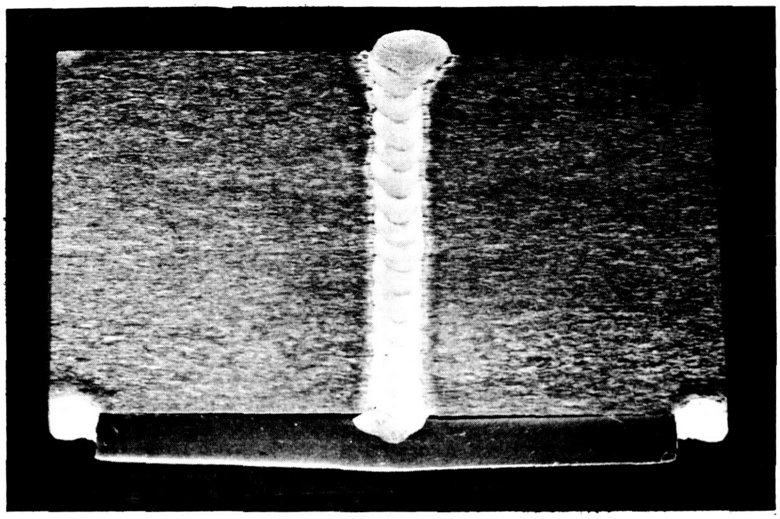
DISCUSSION OF RESULTS

Welding Techniques

Narrow-Gap welds were deposited using three different welding techniques: (1) single-wire-centered, (2) single-wire-offset, and (3) twin-wire technique. Details of welding procedures used and results obtained on all test plates welded during this program are given in Appendix A. An example of a typical individual weld data sheet is shown in Appendix B. Originally, it was planned to do all of the welding with the single-wire-centered technique. The single-wire-offset and twin-wire welding procedures were investigated to eliminate cracking and vertical-position welding problems encountered with the single-wire-centered technique.

Single-Wire-Centered Technique

Figure 22 shows a macrosection of a weld in 2-inch plate deposited using the single-wire-centered procedure. The porosity level in this weld was that of a Class 2 weld according to MSFC-SPEC-259. However, there were lack-of-fusion defects along the root of the weld. These lack-of-fusion defects were attributed to the use of too low a welding current, 195 amperes. Later test welds made using the recommended 210 to 230 amperes were free of lack-of-fusion defects (see macrosection of Weld R-31 shown in Figure 27b).



1X 10% NaOH 6140
+ Conc. HNO_3 Rinse

FIGURE 22. MACROSECTION OF A NARROW-GAP WELD DEPOSITED IN THE FLAT POSITION IN 2-INCH-THICK 2219 ALUMINUM ALLOY PLATE (Plate R-26)

The single-wire-centered procedure given in Table 1 was evaluated only in 1- and 2-inch-thick plate. Several welds were made in 3-inch plate using the single-wire-centered procedure but with 1/16-inch rather than the 3/64-inch-diameter filler wire specified in Table 1. The procedure using 1/16-inch-diameter filler wire was not sufficiently developed to obtain consistently good-quality welds which were free of lack-of-fusion defects. No problems were encountered with weld-metal cracking in the 3-inch-plate welds, however, and the procedure given in Table 1 is believed to be suitable for welding 3-inch-thick plate.

The single-wire-centered procedure developed for flat-position welding was also used satisfactorily for horizontal-position welding. Grade 2 radiographic quality level was also obtained in the horizontal-position welds. The porosity, however, had a tendency to collect along the upper side of the joint. Only the 1- and 2-inch-plate thicknesses were welded in the horizontal position.

Attempts were made to weld in the vertical position by the single-wire-centered technique, but these welds were unsatisfactory. When weld beads were deposited vertically up the weld metal sagged and ran in the joint. Weld beads deposited vertically down were easily controlled and had a good spreading action that promoted sidewall fusion, but these welds were extremely porous. Figure 23 shows a macrosection of a partially welded double-U joint in 5-inch-thick plate. The weld beads were deposited vertically down. A longitudinal weld crack appeared near the center of the weld after about 7/8 inch of weld had been deposited from each side of the plate. Less porous welds in 5-inch-thick plates, deposited by the single-wire-centered technique in the flat position, cracked after about the same amount of weld metal had been deposited; however, the cracks in these welds occurred near the fusion line.

Because of the cracking and vertical-position welding difficulties encountered, work with the single-wire-centered technique was discontinued to work on other approaches to Narrow-Gap welding thick aluminum plate in the vertical position.

Single-Wire Offset

The single-wire-offset technique was first used in an attempt to deposit Narrow-Gap welds in the vertical position. Stringer beads deposited at high travel speeds (40 ipm) were characteristic of this technique. The small weld pools were easily controlled in the vertical position. However, with this technique, each bead left a crevice-type contour that was difficult to fill with the subsequent pass, thus often leaving lack of fusion. An example of this is shown in Figure 24. The crevice left after every pass also made the weld susceptible to cracking between passes. A 5-inch-thick plate was completed by the single-wire-offset technique in the vertical position; however, a cross section of this weld showed that it was cracked even though the fusion was reasonably good.

Single-wire-offset welds were also deposited in the flat position, but these also had lack of fusion. The single-wire-offset technique was abandoned in favor of twin-wire welding.

Twin-Wire Welding Technique

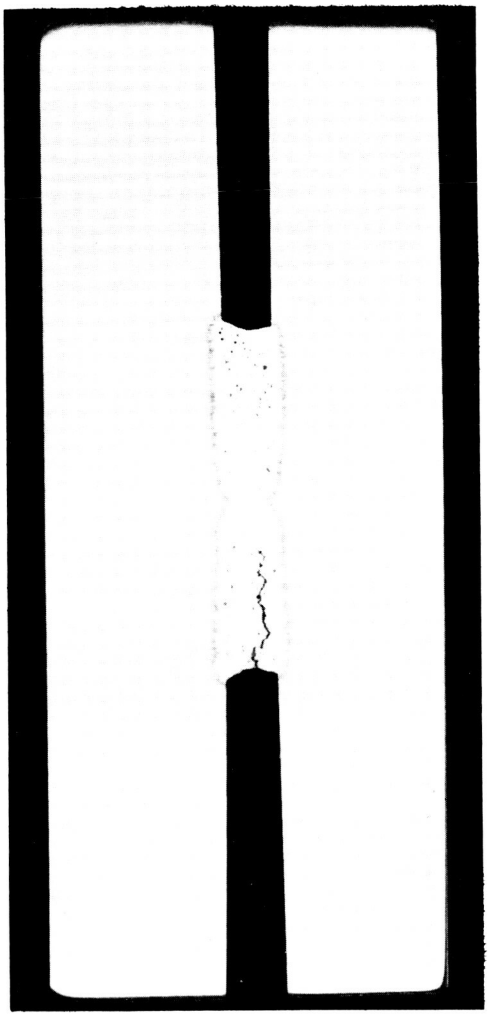
The twin-wire welding technique was considered as a possible approach to eliminate cracking in Narrow-Gap welds in 5-inch-thick plate. It was believed that the more favorable freezing pattern and the smooth contour left after each twin-wire welding pass would reduce the tendency of the weld to crack. The twin-wire technique could be used in the vertical position, since the high travel speeds (40 ipm) limit the size of the weld pools.

It was found that the crevice associated with single-wire-offset welding was more easily penetrated and filled by the twin-wire technique. The leading arc had a preheating effect which aided the penetration of the trailing arc. It was found, however, that the current must be kept high to maintain proper penetration and fusion.

Welds were made in restraint specimens to evaluate the twin-wire technique as a means to eliminate cracking in 5-inch-thick plate. Previously, cracks had appeared in the welds in 5-inch-thick plate after about 2 inches of weld had been deposited, i. e., as the joint became heavily restrained. To save welding time, special restraint specimens were used to evaluate weld cracking. Joints 3/8 inch wide and 2-1/4 inches deep were machined in a solid 5-inch-thick plate. (The modification to control wire cast was added during welding of the first specimen.)

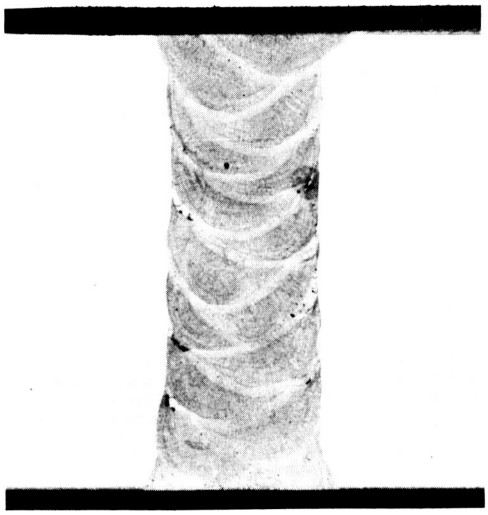
The results from the restraint specimen welds were mixed, in that the third specimen welded (RE-7) cracked, whereas the previous two specimens (RE-5 and RE-6) did not. The crack in Specimen RE-7 was longitudinal and occurred near one side of the joint. It followed a line of porosity in the weld cross section. The specimen was broken open and the fracture surface was examined. Extensive porosity was observed on the fracture surface. At this point, the gas-shielding nozzle was modified to incorporate the end baffles as shown in Figure 16. Two restraint specimens, RE-8 and RE-9, were then welded in the vertical position without cracking. Figure 25a shows a macrosection from Plate RE-8.

A 5-inch-thick plate (Specimen V-20) was then welded using the twin-wire welding technique in the vertical position. A macrosection through this weld is shown in Figure 25b. Figure 26 shows two views of the completed weldment.



1X 10% NaOH 13007
+ HNO_3 Rinse

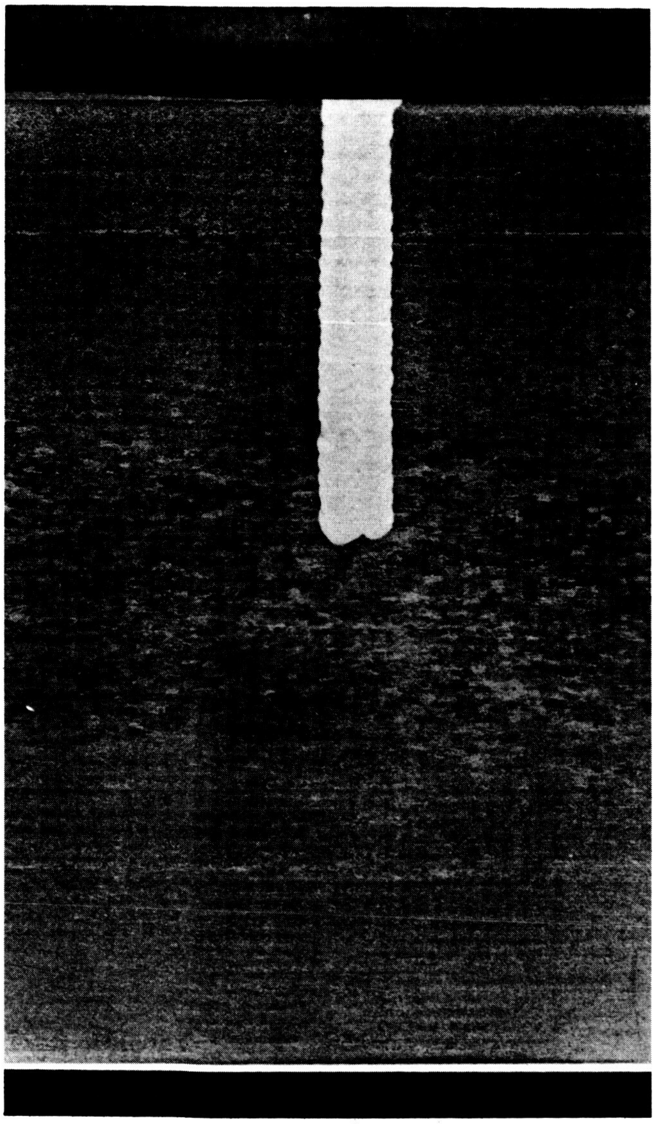
FIGURE 23. PARTIALLY COMPLETED WELD DEPOSITED VERTICALLY DOWN IN A 5-INCH-THICK PLATE (Plate V-7)



2-1/2 X 10% NaOH 17487
+ Conc. HNO_3 Rinse

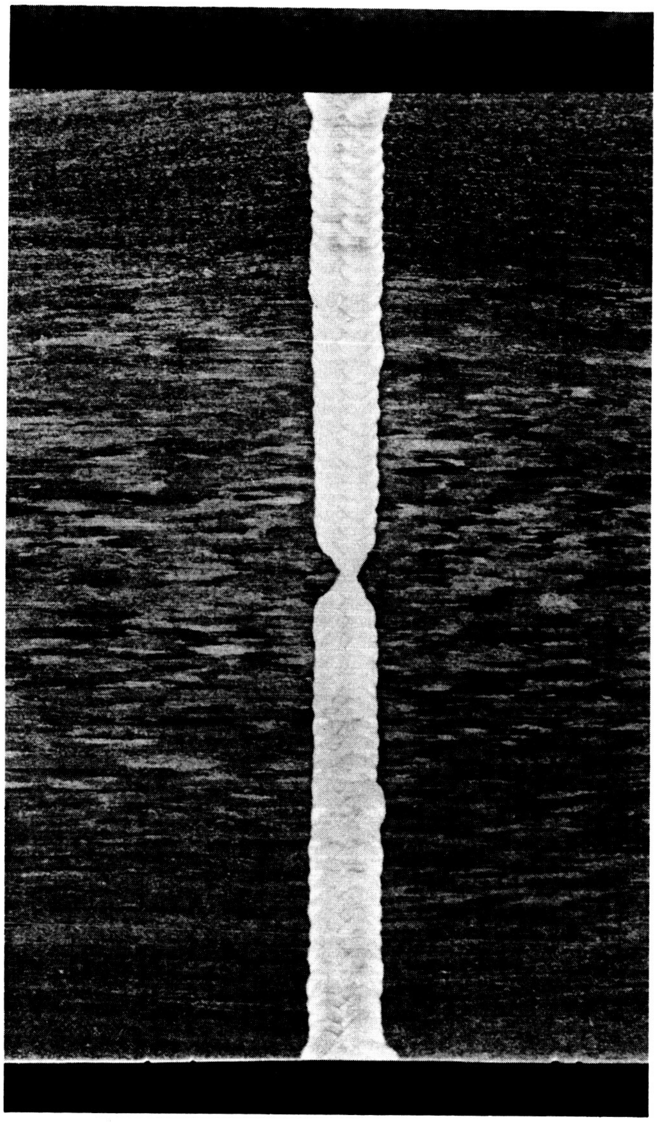
FIGURE 24. MACROSECTION OF NARROW-GAP WELD DEPOSITED IN 1-INCH-THICK 2219-T31 ALUMINUM ALLOY BY THE SINGLE-WIRE-OFFSET TECHNIQUE (Plate V-13)

Note the lack of fusion left at the root of the fillet-type welds.



1X 10% NaOH + Conc. HNO_3 Rinse 19265

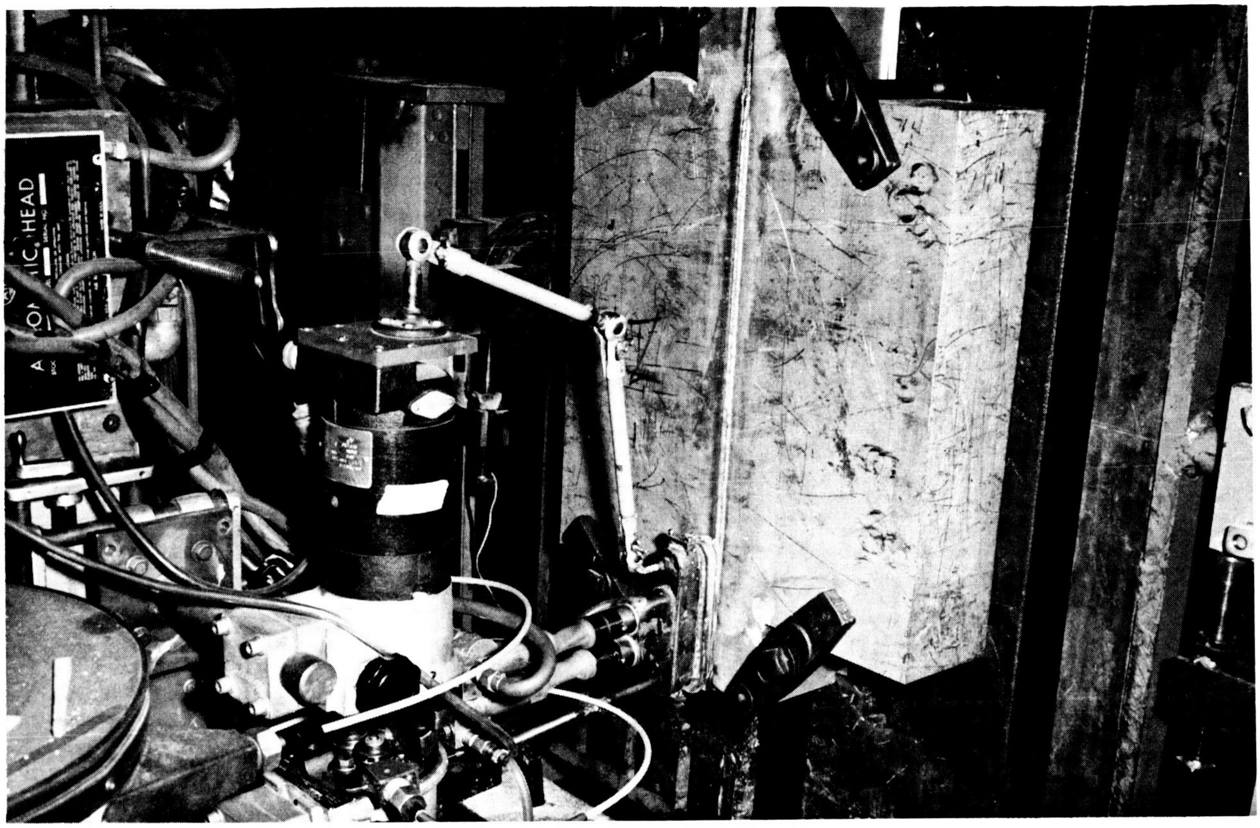
a. Restraint Specimen RE-8



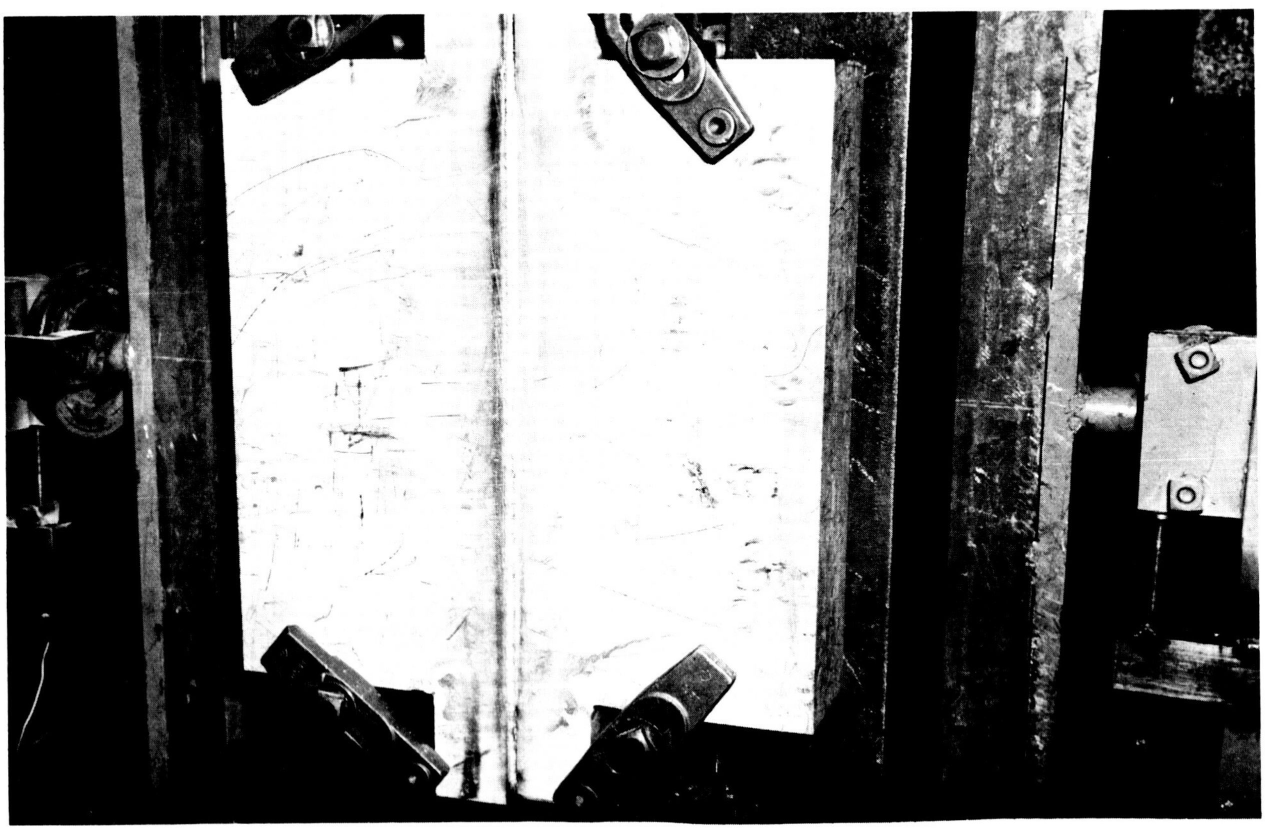
1X 10% NaOH HNO_3 Rinse 19264

b. Butt Weld V-20

FIGURE 25. MACROSECTIONS OF NARROW-GAP WELDS DEPOSITED IN THE VERTICAL POSITION IN 5-INCH-THICK 2219 ALUMINUM ALLOY USING THE TWIN-WIRE TECHNIQUE



18668



18669

FIGURE 26. PHOTOGRAPHS OF SPECIMEN V-20 AFTER COMPLETION

The joint design used for Plate V-20 was a double-U joint with 0.150-inch-thick machined land. The joint was 3/8 inch wide at the root, and 7/16 inch wide at the face. The two root passes of this joint were welded by the single-wire-centered technique to fuse the machined lands together, but the remainder of the weld was deposited by the twin-wire technique.

Weld passes were made alternately on one side of the plate, then the other, for the first 24 weld passes to balance shrinkage forces. Measurements of the joint opening before welding and after each pass showed that there was little shrinkage after 24 passes. From this point on, 2 to 5 passes were made on one side before welding on the other side. The total shrinkage of the joint was 0.095 inch on one side and 0.082 inch on the other side of the plate. The photomacrograph, tensile bars, and bend specimens were taken approximately at the midlength of the weld in Plate V-20.

Twin-wire Narrow-Gap welds were also made in 1 and 2-inch-thick plate in the flat position. Results of the welds made in 2-inch plate are discussed later in the report under the discussion of the effect of preheat. Based on the results obtained in the flat-position welding of 2-inch plate and the vertical-position welding results discussed above, no problems are anticipated in using the twin-wire technique to weld plate thicknesses up to 5 inches in the flat position.

Narrow-Gap Welding Parameters

The effects of a number of the Narrow-Gap welding parameters are discussed in the following sections of this report.

Shielding-Gas Mixtures

Argon, helium, and mixtures of helium and argon were evaluated as shielding gases for Narrow-Gap welding of 2219 aluminum alloy. Argon, and argon-rich helium-argon mixtures were used in the early test welds since it was believed that the heavier argon gas would provide better gas coverage in the deep, narrow-grooved joints. It was found, however, that the arc characteristics were not suitable for Narrow-Gap welding when the helium-argon shielding-gas mixture contained more than 50 percent argon. A mixture of 65 helium-35 argon was found to be the most effective shielding mixture for Narrow-Gap welding aluminum alloy. The choice of the 65 helium-35 argon mixture was based on obtaining the best combination of arc control, bead contour, penetration pattern, arc characteristics, and porosity level.

Shielding-gas mixtures for Narrow-Gap welds were varied from 100 percent argon to 30 argon-70 helium. Narrow-Gap welds were not made using shielding-gas mixtures containing more than 70 percent helium. This upper limit in helium content was based on the results of bead-on-plate tests in which 100 percent helium and mixtures containing close to 100 percent helium caused a digging arc and a poorer, rough, discolored, more oxidized weld bead surface.

When Narrow-Gap welding with pure argon or argon-rich shielding-gas mixtures, the arc was not easily controllable. With short arc lengths, there was an excessive amount of weld spatter, and the weld bead had a rougher surface. When the arc length was increased enough to significantly decrease the weld spatter, the arc wandered to the joint sidewalls and resulted in lack of fusion.

In general, welds deposited using 50 to 70 percent helium shielding gas were found to be less porous than welds deposited using a mixture made up predominantly of argon. Macrosections of Narrow-Gap welds deposited using shielding-gas mixtures of 70 argon-30 helium and 65 helium-35 argon are shown in Figure 27. These welds were made using the same heat input (approximately 13,000 joules per inch). As shown in Figure 27, the welds made using 70 argon-30 helium shielding gas contained more porosity. This weld also exhibited poorer penetration into the joint sidewall, and a number of lack-of-fusion defects are visible in this cross section. Attempts were made to improve the penetration and perhaps decrease the porosity in 70 argon-30 helium shielded welds by using higher welding current. Satisfactory high current welding conditions, however, could not be established using the argon-rich shielding-gas mixtures.

The improved weld-metal soundness and Narrow-Gap operating conditions obtained with the high helium-gas mixtures as compared with those obtained with the high argon-gas mixtures can be attributed to a number of facts:

(1) The weld beads tend to have greater penetration near the edge, therefore, assure better penetration into the sides of the Narrow-Gap joint.

(2) A spray mode of metal transfer can be maintained even though the arc length is short.

(3) The voltage to arc-length ratio is higher, thereby producing a more concentrated source of heat.

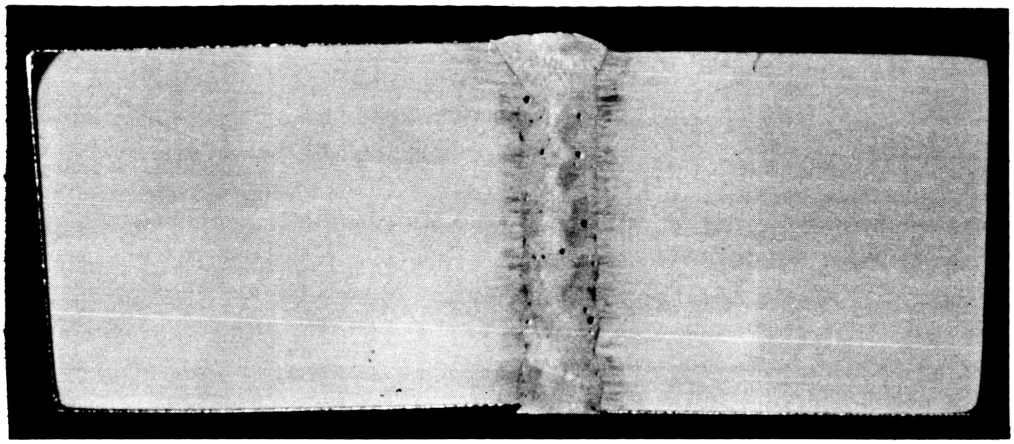
Arc Voltage

In general, the arc voltage must be more closely controlled in Narrow-Gap welding than in conventional gas-metal-arc welding. The arc voltage and the arc length are directly related. In Narrow-Gap welding as in conventional gas-metal-arc welding an extremely short arc length causes excessive weld spatter and an unstable arc. Also, if the arc is extremely short, it is impossible to establish the spray-transfer current characteristic required for Narrow-Gap welding. On the other hand, the Narrow-Gap welding arc must be kept short enough to be controllable in the narrower joint. If the arc length becomes longer than the distance from the filler wire to the sidewall, there is danger that the arc will wander to one sidewall or the other.

Narrow-Gap welds were deposited at a number of different arc voltage values, ranging from 19 to 27 volts. A list of the voltage ranges investigated and recommended voltage ranges for each welding position and welding technique is given in Table 4.

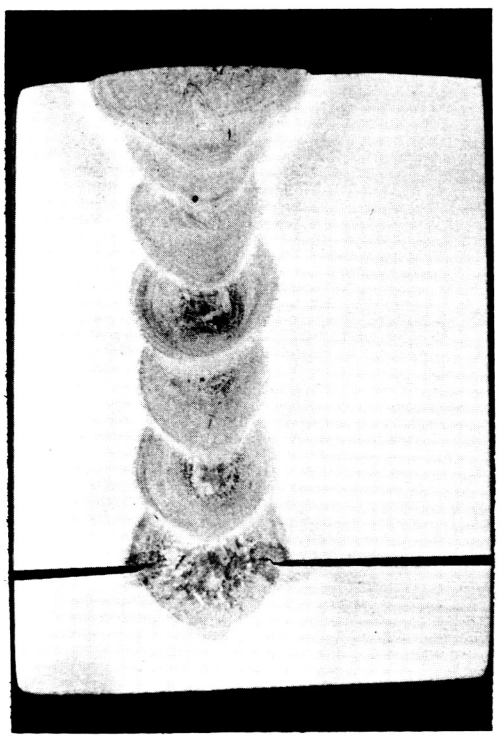
Current

The current ranges investigated during this program were 150 to 275 amperes for 3/64-inch-diameter wire and 170 to 290 amperes for 1/16-inch-diameter wire. The use of too low a current caused lack of fusion, unstable arc, and porosity in Narrow-Gap welds. The use of very high current caused the arc to wander and to have a deep penetration in the center of the weld accompanied by eruption and spatter from the weld pool.



2X 10% NaOH 5300
HNO_3 Rinse

a. Weld R4 Deposited Using 70%A-30%He Shielding Gas



2-1/2X 10% NaOH 17491
HNO_3 Rinse

b. Weld R31 Deposited Using 65%He-35%A Shielding Gas

FIGURE 27. MACROSECTIONS OF NARROW-GAP WELDS DEPOSITED IN 1-INCH-THICK 2219-T31 ALUMINUM PLATE USING HIGH ARGON (top) AND HIGH HELIUM (bottom) He-A SHIELDING GAS

TABLE 4. LIST OF ARC-VOLTAGE RANGES USED FOR DEPOSITING NARROW-GAP WELDS

	Welding Position			
	Flat		Horizontal	Vertical
Technique Used	Single-wire-centered	Twin-wire	Single-wire-centered	Twin-wire
Arc Voltage Range Investigated	21 to 27	19 to 23	22 to 26	19 to 23
Recommended Arc Voltage Range	23 to 25	20 to 22	23 to 24	20 to 22

In general, it was necessary to use higher currents when welding with the single-wire-centered technique than with the twin-wire technique. The single-wire-centered weld bead must completely bridge the joint fusing to both sidewalls and to the bottom of the joint. The twin-wire weld beads are a fillet-type weld and only fuse to one sidewall and to the bottom of the joint.

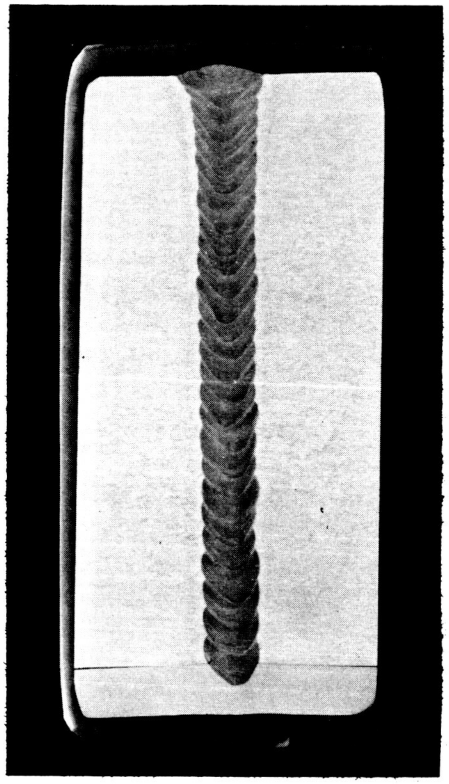
The proper welding current, of course, depends upon the size of the filler wire used. In general, the current and the voltage must be adjusted together to establish a spray-arc characteristic with a short arc length. The optimum current for 3/64-inch-diameter wire in twin-wire welding was found to be 180 to 190 amperes. The optimum current established for single-wire-centered welding for 3/64-inch-diameter wire was 210 to 230 amperes.

Filler-Wire Diameter

Two filler wire sizes, 3/64 and 1/16-inch diameter, were evaluated for Narrow-Gap welding of aluminum. Only the 3/64-inch-diameter wire was shown to be satisfactory and is specified in the recommended welding procedures.

Results of a number of test welds made in this program indicate satisfactory single-wire-centered welding conditions might be established using 1/16-inch-diameter filler wire in the flat position. Weld beads deposited using the 1/16-inch-diameter wire have good visual appearance. The beads appeared to spread well in the joint and fused to both sidewalls.

A macrosection of a flat-position weld made using single-wire-centered technique with 1/16-inch-diameter filler wire is shown in Figure 28. This weld was deposited using an enclosure to improve the shielding-gas coverage. The weld beads exhibit good sidewall fusion with very little porosity. A number of attempts were made to use these same welding conditions in subsequent test plates. These later welds, however, were made in thicker plate or in the vertical position and were unsatisfactory due to weld cracking or excessive running of the weld puddle. The same conditions were not re-checked for welding 1 to 3-inch-thick plate in the flat position. Since Test Plate F-10 was welded in an enclosure and the mechanical properties of the weld were not determined, the consistency of the welding procedure was not checked and the procedure determination with 1/16-inch-diameter filler wire is not considered complete.



1X 9853

FIGURE 28. MACROSECTION OF NARROW-GAP WELD IN 3-INCH-THICK 2219 ALUMINUM DEPOSITED USING 1/16-INCH-DIAMETER 2319 FILLER WIRE (Test Weld F-10)

The weld was deposited in the flat position using an enclosure around the plate to improve gas shielding.

Further welding studies should be conducted using 1/16-inch-diameter filler wire for flat-position welding. It is believed that the use of this larger size wire would offer a possible advantage of allowing the use of wider joint gaps than possible with the 3/64-inch-diameter wire. In certain instances, the wider joint gap may be advantageous to provide better accessibility for the contact tube and for shielding gas.

The 3/64-inch-diameter filler wire with its smaller weld puddle was better suited to horizontal-position welding than 1/16-inch-diameter filler wire. Two test plates were welded in the horizontal position using the larger size wire. The beads in these plates tended to sag in the joint or leave unfused areas at the sidewalls of the upper plate. A number of plates were welded in the horizontal position using 3/64-inch-diameter wire. The puddle was controllable; yet fusion to the upper side of the joint was good.

The 3/64-inch-diameter filler wire is also believed to be best suited for twin-wire welding in either the flat or vertical positions. The desired narrow fillet-type beads could be obtained with the 3/64-inch-diameter wire, and the welding puddle was controllable for vertical-position welding.

Joint Gap

The minimum joint width is determined by the size of the contact tube. The joint must be wide enough to provide accessibility for the contact tube to be inserted into the joint with adequate clearance on each side. The maximum joint gap is dictated both by economy and by the width of the deposited weld bead. The bead must completely fill the joint and fuse to both sidewalls.

The 1/4-inch-wide joint gap used for single-wire-centered welding using a 3/64-inch-diameter wire was predetermined on the basis of contact tube size. The 1/4-inch width is believed to be a practical minimum for the size of the contact tubes used. During welding studies made using 3/64-inch-diameter wire and the single-wire-centered technique, it was found that the 1/4-inch-wide gap is also close to the upper limit which will assure adequate sidewall fusion. Single-wire-centered weld beads were deposited in a 5-inch-thick plate which had been prepared with joints having a small included angle. When welding with the 3/64-inch filler wire in these tapered joints, it was observed that the sidewall fusion became poor when the joint width exceeded 9/32 of an inch.

As mentioned previously, welds were made in 5/16-inch-wide joints using 1/16-inch-diameter filler wire with a single-wire-centered welding technique. Attempts were made to weld in a 3/8-inch-wide joint using 1/16-inch-diameter filler wire. However, these welds exhibited lack-of-fusion defects. The maximum joint width weldable with the 1/16-inch-diameter wire is therefore between 5/16 and 3/8 inch. However, this limit has not been determined.

The joint width used for twin-wire welding in this program was nominally 3/8 inch. This wider joint gap was dictated primarily by the need for accessibility of the contact tubes. In twin-wire welding, the contact tubes were bent or angled toward the sidewall to provide better root fusion. If the wire-cast system could be perfected so that the angled contact tube was not necessary, a narrower joint gap might be used.

The joint widths measured prior to depositing each weld layer during twin-wire welding varied between 11/32 and 13/32 inch. This joint gap variation did not affect the quality of the weld. The actual upper and lower tolerance limit for joint gap variation, however, was not determined with precision.

Travel Speed

After the proper arc characteristics are established, the weld travel speed must be adjusted to obtain the proper size and shape of bead. Optimum travel speed will vary with the welding technique, wire size, joint gap, and welding position.

When welding with a single-wire-centered technique, the weld bead must be wide enough to fuse to both sides of the joint. Weld beads can be widened to some extent by using slower travel speeds. When a travel speed is too slow, however, it was found that excessive weld-metal buildup cushioned the arc and caused lack of fusion to the joint sidewalls. Although the weld beads spanned the joint, it tended to solidify against the cold joint surface without fusion.

The optimum travel speed for welding in the flat position using the 3/64-inch-diameter wire and the single-wire-centered technique was 24 to 26 inches per minute. Higher travel speeds were necessary to deposit the fillet-type stringer beads required in twin-wire welding. The optimum travel speed for twin-wire welding in the vertical position was about 40 inches per minute. Slightly slower travel speeds, about 37 inches per minute, were used satisfactorily in the flat position.

Contact-Tube Position

In Narrow-Gap welding, the contact tube is inserted into the weld joint. Contact-tube-to-work distance, CTWD, is the distance from the end of the contact tube to the bottom surface of the joint or to the surface of the previously deposited weld beads. It is desirable to keep the CTWD as short as possible so that the filler wire is accurately positioned in the narrow joint. If the CTWD was too short, there was a danger of burn-back to the contact tube if the wire-feed speed fluctuated momentarily. Also with excessively short CTWD, there is an increase in wire stoppages due to spatter collecting at the end of the contact tube. When the CTWD was too long, it was more difficult to obtain proper position of the fine aluminum wire in the weld joint. A CTWD of 1/2 to 9/16 inch was found to be suitable for Narrow-Gap welding of aluminum.

The other important dimension with respect to contact-tube position in the joint is the distance to the joint sidewall. When welding with a single-wire-centered technique the contact tip should be positioned as accurately as possible in the center of the joint. For single-wire-offset or twin-wire welding the contact tube(s) should be positioned so that the intersection of the center of the wire and the bottom of the joint or the surface of the previously deposited bead is 1/16 inch from the joint sidewall (shown in Figure 21).

In twin-wire welding, the leading and trailing wires were located about 1-1/4 inches apart in the joint.

Welding-Head Angle

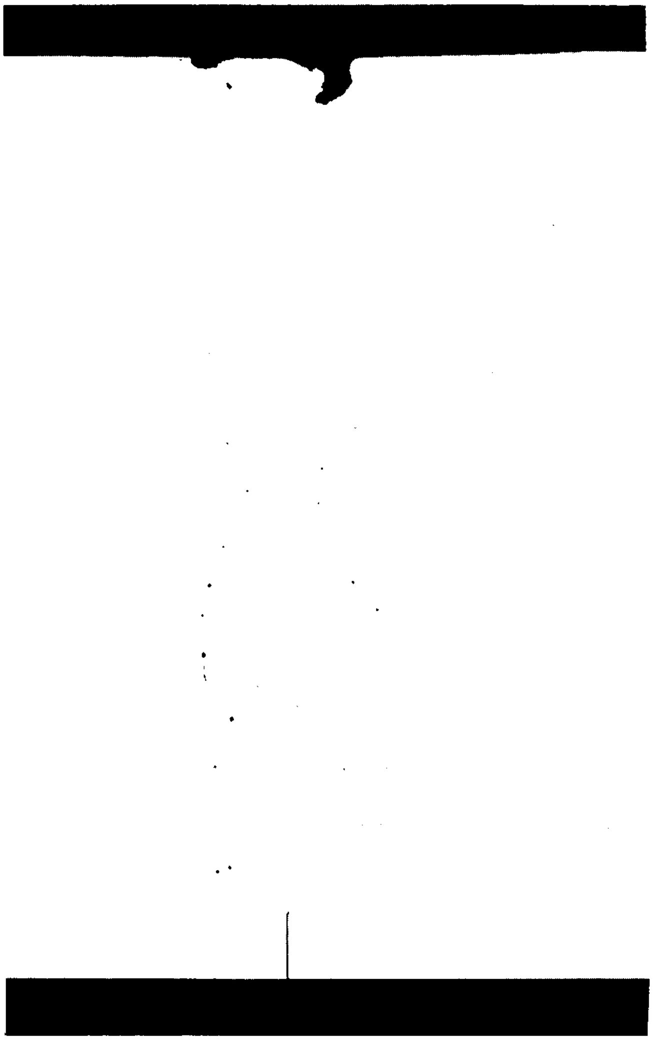
Welding-head angle is the angle the torch-barrel assembly makes with a line perpendicular to the plate surface in the plane perpendicular to the joint center line. Most of the test welds were deposited using a 5 to 7-degree lagging head angle on the torch. The use of a lagging head angle tended to spread the weld beam promoting good sidewall fusion and improved surface smoothness.

Effect of Preheat and Interpass Temperature

The use of preheat was considered as a possible means to eliminate weld cracking. Two 2-inch-thick test plates, one with and one without preheat, were welded to evaluate the effect of a 300 F preheat and interpass temperature on mechanical properties of the weld. These welds were made in the flat position using the twin-wire welding technique. The 12-inch-long plates were machined to provide a 3/8-inch-wide joint with a 1/4-inch land at the bottom for weld backing. No attempt was made to obtain a full-penetration weld in this joint preparation.

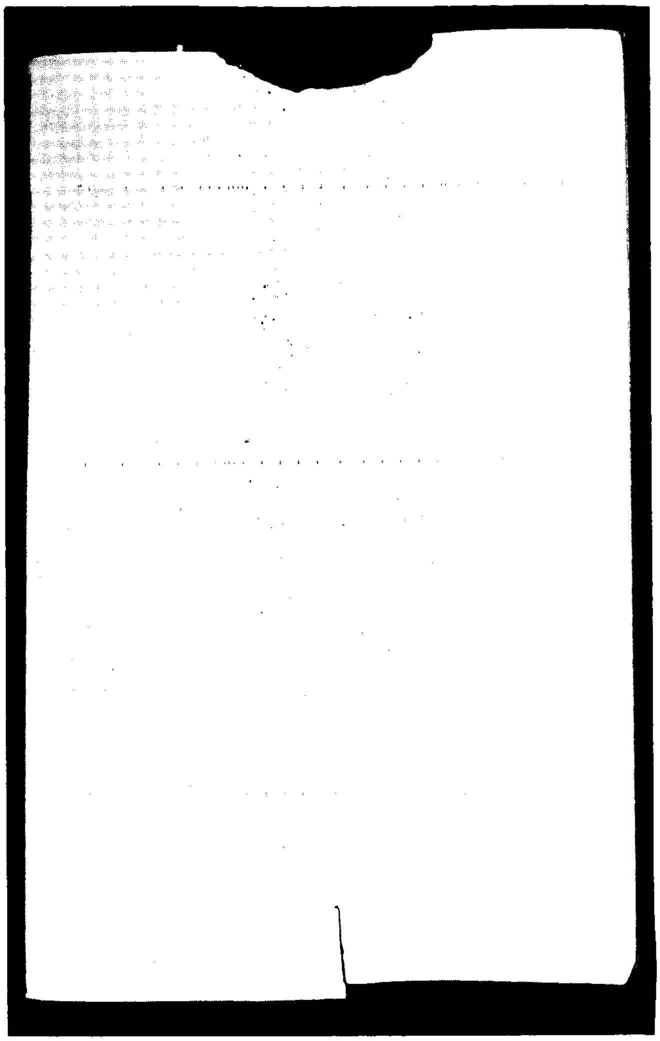
The welding conditions used for the preheated plate (F-24) were essentially the same as those for the non-preheated plate (F-26). Three beads in the non-preheated plate were deposited using the single-wire-offset technique while one of the welding heads was temporarily out of order. These beads did not appear to fuse well at the sidewalls. Sidewall fusion of the twin-wire weld beads in this plate appeared to be good.

Metallographic cross sections of the two welds are shown in Figure 29. These sections were only lightly etched for microhardness testing. Both of these sections were taken near the end of the weld where the joint was not quite filled. Lack of fusion



2-1/2X 10% NaOH + Conc. HNO_3 Rinse 17498

a. Non-Preheated Weld (F-24)



2-1/2X 10% NaOH + Conc. HNO_3 Rinse 17497

b. Weld Preheated to 300-350 F (F-26)

FIGURE 29. PHOTOMACROGRAPHS OF WELD CROSS SECTIONS FROM TEST PLATES WELDED TO EVALUATE THE EFFECT OF 300 F PREHEAT

Welds were deposited in the flat position using the twin-wire Narrow-Gap welding process. Indentations from Tukon hardness traverses are visible across the top, middle, and bottom of the welds.

to the joint sidewall is visible in the photomacrograph of the non-preheated weld shown in Figure 29. This bead was deposited with the single-wire-offset technique as discussed above. In general, the weld deposited in the preheated plate has more uniform sidewall fusion than the weld in the non-preheated plate.

Microhardness traverses were made across the weld and heat-affected zone in each of the weld sections shown in Figure 29. The hardness readings were taken using a Tukon hardness tester with 1-kg load. Indentations were made at 0.025 to 0.075-centimeter intervals as required to obtain adequate definition of the hardness variation. The indentations from the microhardness traverses at the top, middle, and bottom of the weld can be seen in the photomicrographs shown in Figure 29.

Figure 30 is a plot of the hardnesses taken through the top, middle, and bottom of the weld made without preheat. Similarly, Figure 31 compares the hardness in the three levels of the plate welded with 300 F preheat. As shown in Figures 30 and 31, there was no significant difference in hardness in the three levels in either the preheated or non-preheated plate outside of the fusion zone.

The hardness traverses through the middle of the weld in the preheated and non-preheated plates are compared in Figure 32. As shown in this figure, the hardness of the weld, the heat-affected zone and base metal, in the preheated plate is significantly lower than that of the non-preheated plate. Additional hardness readings were taken in the base metal approximately 3-1/2 inches from the bond line of each weld. The hardness in the preheated plate averaged 132 KHN, 11 KHN lower than the 143 KHN average hardness in the plate welded without preheat. A logical explanation for the observed hardness variations attributed to preheating is not apparent. The time-temperature cycle used in the preheat experiments would be expected to closely simulate the normal artificial aging treatment given to T31 material to develop the T81 temper. Obviously, the preheat cycle has not resulted in the expected increase in hardness that should accompany aging.

Two guided-side-bend specimens were tested from the preheated and non-preheated test plates. These specimens were 1/8 inch thick, 1-1/2 inches wide, and 6 inches long. The specimens were bent around a series of dies, starting with a 3-inch radius die and progressing to a 3/8-inch radius die. The specimens were dye checked after each bend to determine whether any cracks formed in the weld zone. All four specimens failed in the weld when bent in the 3/8-inch radius die. The total percent elongation corresponding to the bend around the 1/2-inch radius die, the minimum radius before failure, was calculated to be about 10 percent.

Two transverse-weld reduced-section tensile tests were run on each test plate. The specimens were taken from the midthickness of the weld. The results of these tensile tests indicate the tensile strength of the preheated test plate was significantly lower than that of the non-preheated test plate. The average tensile strengths of specimens from the non-preheated plate was 40.6 ksi as compared with 37.1 ksi in specimens from the preheated test plate. (Detailed test results are contained in Table 5 which lists the mechanical properties obtained on all specimens tested during this program.) The specimens from the preheated weld failed through the center of the weld; specimens from the plate welded without preheat also broke in the weld but with an irregular pattern.

Results of these studies indicated moderate preheat and interpass could seriously affect joint properties.* Based on the favorable results obtained in eliminating weld

* This conclusion should be restricted to the T31 or T351 tempers used in this program.

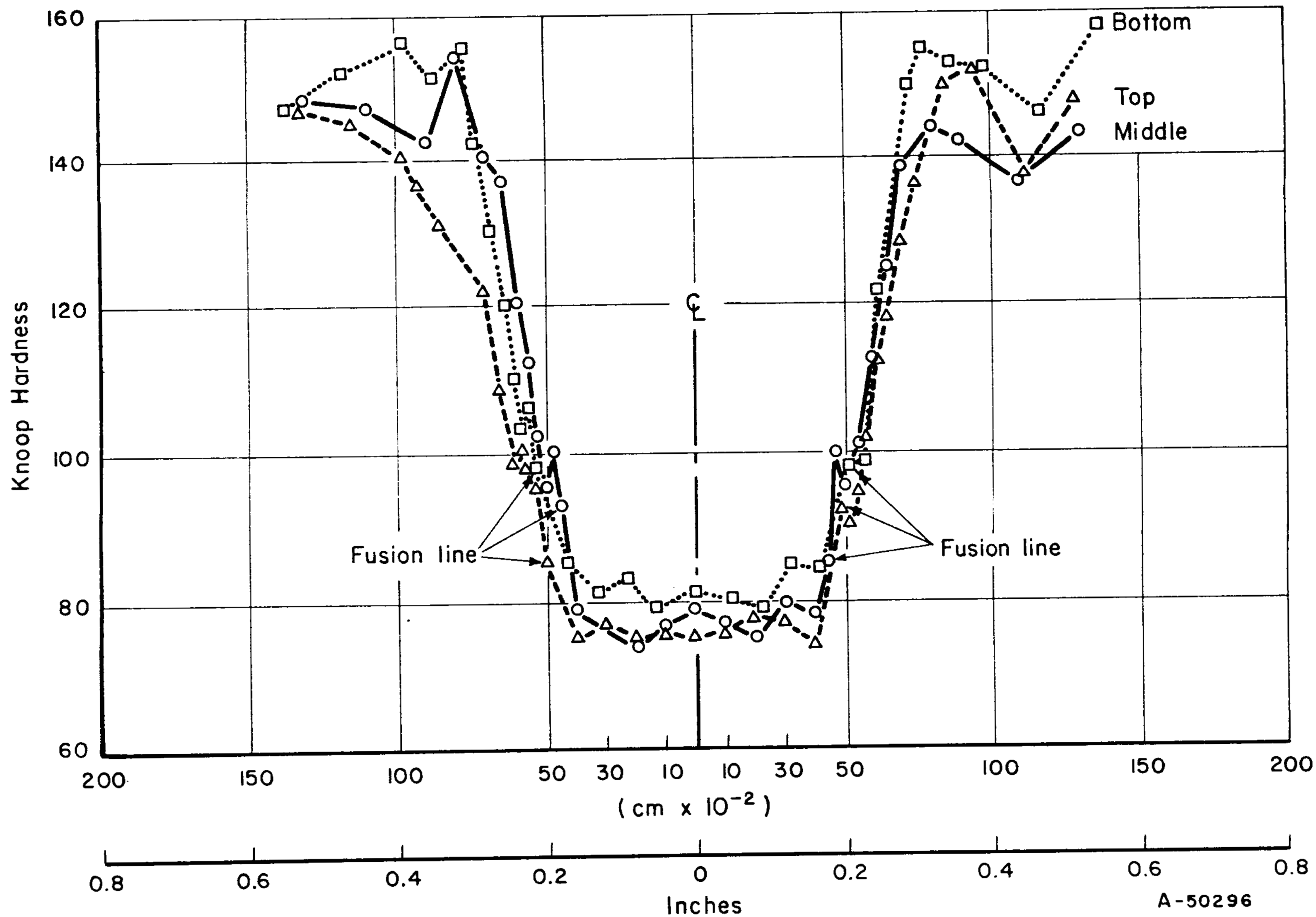


FIGURE 30. HARDNESS OF WELD ZONE IN 2-INCH-THICK 2219-T31 ALUMINUM ALLOY PLATE (F-24) WELDED WITH NO PREHEAT

Traverses across the top, middle and bottom of the weld were made using a Knoop Penetrator and a 1-kg load.

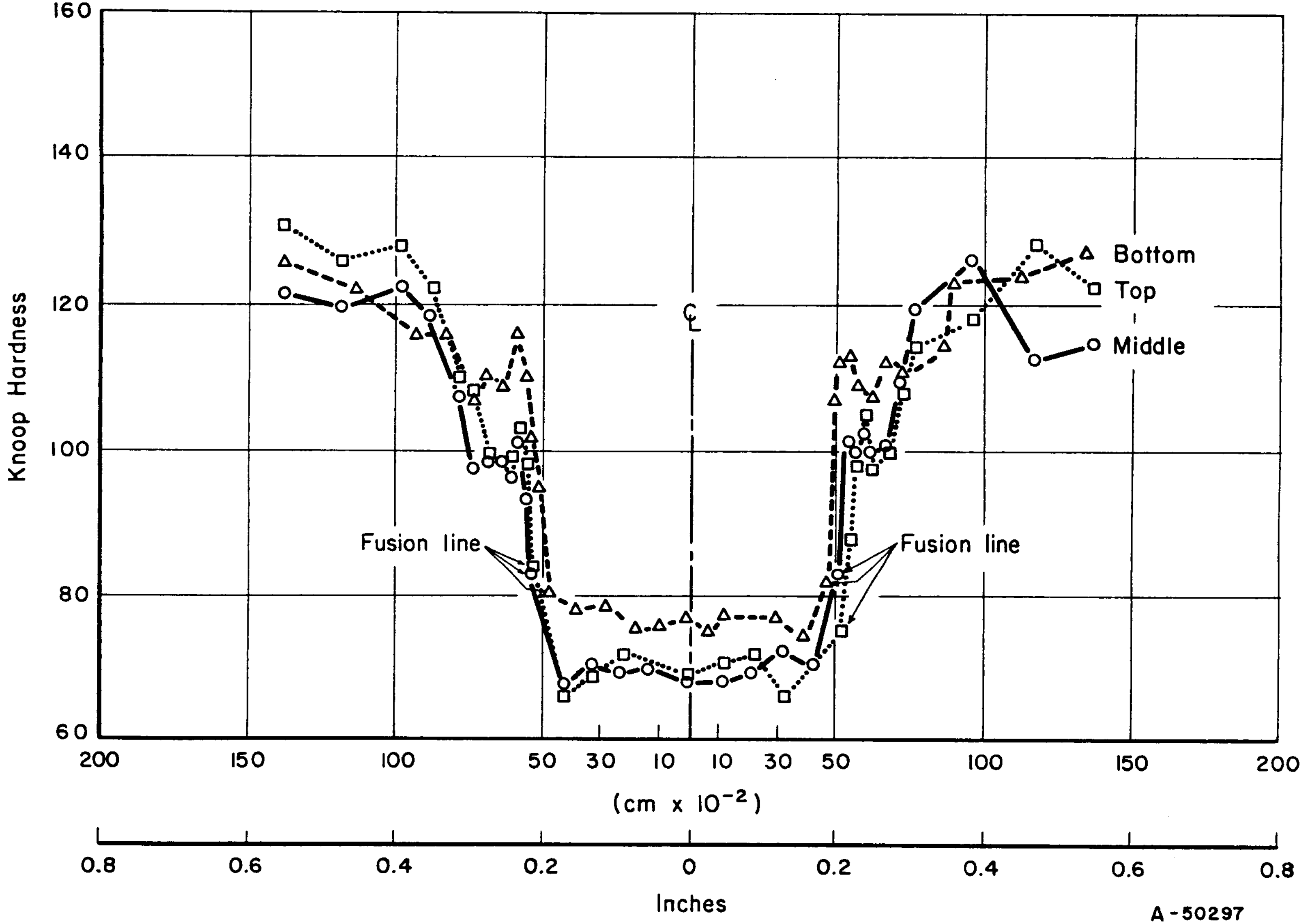


FIGURE 31. HARDNESS OF THE WELD ZONE IN 2-INCH 2219-T31 ALUMINUM ALLOY PLATE (F-26) WELDED USING 300 F PREHEAT

Traverses were made across the top, middle and bottom of the weld using a Knoop Penetrator and a 1-kg load.

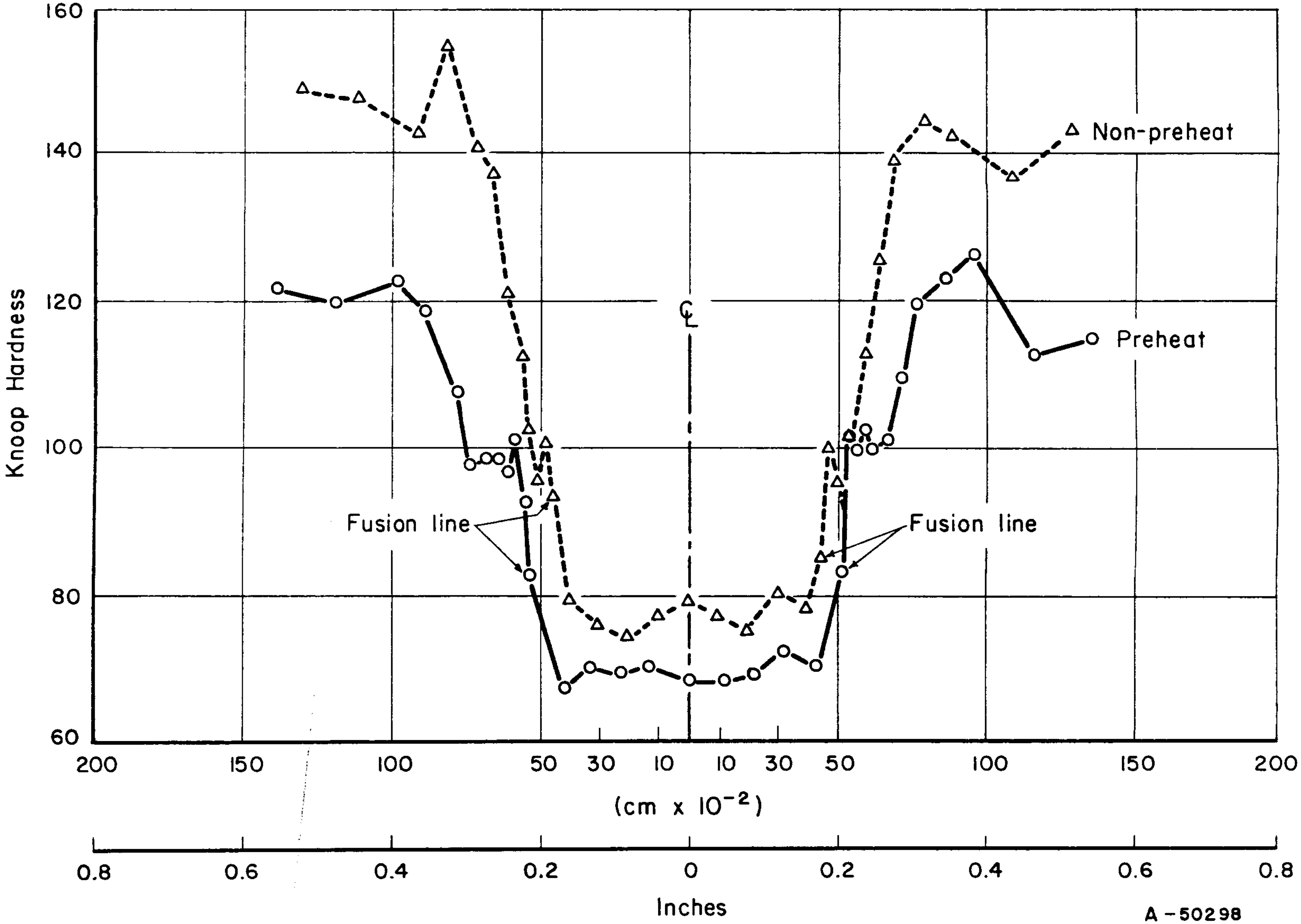


FIGURE 32. COMPARISON OF HARDNESS IN THE WELD ZONE OF NARROW-GAP WELDS IN 2-INCH-THICK 2219-T31 ALUMINUM ALLOY WELDED WITH NO PREHEAT AND WITH 300 F PREHEAT

The hardness was measured across the middle of each weld using a Knoop Penetrator and a 1-kg load.

TABLE 5. MECHANICAL PROPERTIES OF NARROW-GAP WELDS IN 2219-T31 ALUMINUM PLATE[a]

Test Plate Number	Plate Thickness, inch	Weld Position	Weld Technique	Specimen Type	Ultimate Tensile Strength, ksi	Yield Strength 0.2% Offset, ksi	Elongation, percent 1/2 in.	Elongation, percent 1 in.	Elongation, percent 2 in.	Tensile Joint Efficiency[b]	Defects in Fracture Surface	Bend Test Results Min Die Radius, inch	Bend Test Results Elongation[c], percent	Average Weld Metal Hardness[d], Rockwell B
F-25	3	Flat	SWC[e]	Rect	31.6	25.1	10	5	3	54.8	LF[g]	1	6	27.2
				5/8" x 1"	31.0	25.0	8	4	2.5	53.8	LF	1	6	
					34.0	25.0	8	5	3.5	59.0	LF			
H-4	2	Horizontal	SWC	Round	41.6	24.8			5.8	75.6	--			
				0.505"	42.2	24.6			5.8	76.6	--			
					41.3	24.3			5.8	75.1	--			
F-27	3	Vertical	TW[f]	Rect	34.4	25.4	9	5	3	59.7	LF	1	6	24.5
				5/8" x 5/8"	33.3	25.8	9	5	3	57.8	LF	1	6	
F-24	2	Flat	TW	Rect	41.2	28.3			4.0	74.7	--	1/2	9.3	27.3
				5/8" x 1"	40.0	28.1			4.0	73.7	--	1/2	10.0	
F-26	2	Flat	TW	Rect	35.5	25.7			3.5	64.6	--	1/2	9.7	23.7
(300 F preheat)				5/8" x 1"	38.7	23.8			4.5	70.4	--	1/2	10.3	
V-20	5	Vertical	TW	Rect	38.3	26.7	12	7	4.5	66.4	LF			30.1
				5/8" x 1"	38.9	31.1	10	7	4.5	67.5	LF			
					41.9	27.1	14	9	6	72.7	--			

(a) All welds were deposited using 2319 filler wire.
(b) Percentage ratio of weld metal tensile strength to base metal tensile strength. Joint efficiency of welds in 2-in. plate is based on an average base metal strength of 55,000 psi as determined from tests of 2-in. plate material conducted during this program. Joint efficiency of welds in 3 and 5-in. plate is based on an average base metal strength of 57,700 psi as determined from tests of 5-in. plate material conducted during this program.
(c) Elongation calculated from formula discussed in "Testing Procedure" section of this report.
(d) Hardness measured using Rockwell Hardness Tester, 1/16-in. ball, 100-kg load.
(e) SWC - single wire centered.
(f) TW - twin wire.
(g) LF - lack of fusion.

cracking using the twin-wire welding technique without preheat, no further studies were made of weld preheat.

Mechanical Properties

The results of transverse-weld tensile tests, transverse-weld side bend tests, and weld-metal hardness tests conducted on a number of the 2219-T31 Narrow-Gap welded test plates are summarized in Table 5. In all cases, the tensile strength of the Narrow-Gap welds exceeded 40.0 ksi provided the weld was free of linear defects and was welded without preheat.

All of the tensile specimens failed in the weld, usually near the bond. The tensile strength ranged from 31.0 to 42.2 ksi. As noted in Table 5, specimens which failed below 40.0 ksi contained lack-of-fusion defects, or in the case of specimens from Plate F-26 were welded using 300 to 350 F preheat and interpass temperatures. These low tensile properties in weld specimens containing defects may be partially attributed to the use of the small cross-section tensile specimens as listed in Table 5. Those specimens which were free of lack-of-fusion defects exhibited tensile strengths ranging from 40.0 to 42.2 ksi and tensile joint efficiencies of 72.7 to 76.6 percent. These strengths exceed the 35 ksi minimum tensile strength accepted as the realistic minimum tensile strength for as-welded 2219-T87 aluminum.(2)

Figure 33 shows the fracture surface of the tensile specimens taken from Plate V-20. Specimens B-1 and B-2 taken near one surface and near the center of the plate, respectively, each exhibit lack-of-fusion defects. Specimen B-1 also contained considerable porosity. Specimens B-1 and B-2 failed at 38.3 and 38.9 ksi, respectively. Specimen B-3, taken near the opposite surface of the plate, had very few visible defects in the tensile fracture surface and failed at 41.9 ksi.

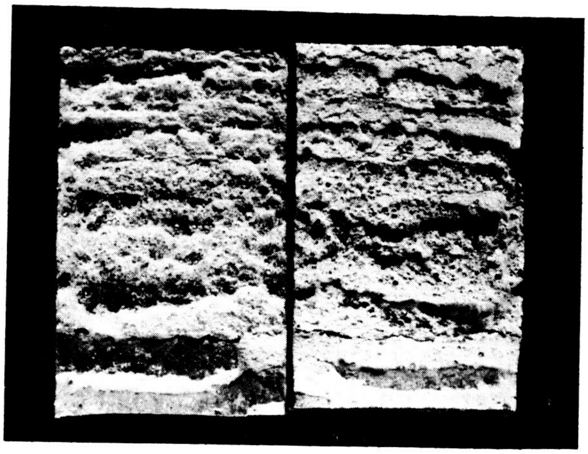
The tensile elongation, measured in a 2-inch gage length, ranged from 2.5 to 6.0 percent in all specimens and from 3.5 to 6 percent in welds which were free of linear defects. The percent elongation measured in 1/2- and 1-inch gage lengths was higher than that measured in the 2-inch gage length. Less unaffected base metal is included in the shorter gage lengths. Since the weld and heat-affected zone is more ductile than the base metal, the elongation values are higher the shorter the gage length used. Elongation measurements made in 1/2-inch gage lengths indicate the ductility in the weld and adjacent heat-affected zone ranged from 8 to 12 percent in specimens which had linear defects in the weld.

The tensile properties obtained in the Narrow-Gap welds tested probably represent minimum values obtainable from this type of weld for the following reasons:*

(1) Small test specimens, such as those used in this program, generally result in lower tensile properties than full-section specimens.(1)

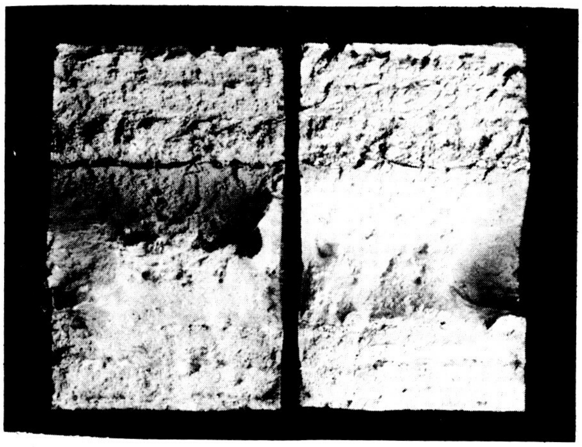
(2) The potential improvement in joint strength that should result from the narrow weld joint and heat-affected zone was not determined.

*Tests of the type required to establish the validity of these reasons were not included as a part of this program. Suitable tests should be included in any future study of this or similar processes.



B-1

2X 19610



B-2

2X 19609

B-3

2X 19611

FIGURE 33. FRACTURE SURFACES OF TRANSVERSE TENSILE BARS FROM A NARROW-GAP WELD IN 5-INCH-THICK 2219-T31 ALUMINUM ALLOY (Plate V-20)

The fractures occurred in the weld metal near the bond line.

The percent elongation calculated from the bend-test results range from 6 to 10 percent. In welds that did not contain lack-of-fusion defects, it ranged from 9.3 to 10.3 percent.

The weld-metal hardness of the Narrow-Gap welds was measured on transverse weld cross sections. Average values were shown in Table 5. Rockwell B hardness traverses also were taken along the centerline of some welds. A sketch of the location and values of the hardness traverse made on Weld V-20 is shown in Figure 34. This weld was deposited in 5-inch-thick plate using the twin-wire technique and welding from two sides. As noted in Figure 34, the hardness of the weld progressively decreased from the center to the surfaces of the plate; the weld metal deposited first had a higher hardness than the weld deposited in later passes. This behavior was found to be typical of all of the Narrow-Gap welds tested. In plates welded from one side, the weld-metal hardness progressively decreased from about R_B-30 at the root side to R_B-24 at the face side of the weld. Apparently, the heat from the later weld passes had an aging effect on the first weld metal deposited.

Tukon hardness traverses made across weld joints were discussed previously in the section on preheat (see Figures 30-32). These hardness measurements (from this study) compare favorably with similar measurements reported for electron-beam welds in 2219-T81 material.(1) The estimated heat-affected zone width of Narrow-Gap welds based on hardness traverses is about half the weld width on either side of the joint. Thus, the total width subjected to detectable property changes in a Narrow-Bap weld is about 2w, where w equals the fusion zone width. The corresponding width in electron-beam weldments was reported to be 3w.(1)

Additional mechanical property tests were made on sections of a 5-inch-thick weld (V-20). These tests were made to determine the effect of aging after welding and in an attempt to establish strength of a full weld section. Figure 35 shows the location of these specimens in relation to the weld.

Slabs F and O were aged for 24 hours at 325 F (T81 condition). Rectangular tension specimens 1 inch wide x 1/4 inch thick were then cut as shown. Slab J was intended for a full section tension test; however, it was necessary to cut this slab into 2 specimens 2-1/2 inches wide x 1/4 inch thick. Lack-of-fusion areas in each specimen (J-1 and J-2) were removed by drilling a 1/16-inch-diameter hole through the slab.

The results of these tests are shown in Table 6. The aging treatment resulted in a decided improvement in ultimate strength and slightly lower elongation, as expected. The specimen that failed below 40 ksi (O-1) exhibited considerable porosity on the fracture surface. Slight porosity was apparent on a few other fractures. Tests of the as-welded extra wide specimens resulted in low ultimate strength. These results were probably strongly influenced by the specimen geometry which was definitely unusual. Testing to determine the full thickness strength will probably require using a specimen about 5 inches square and at least 30 inches long. Equipment and material were not readily available for such tests during this program

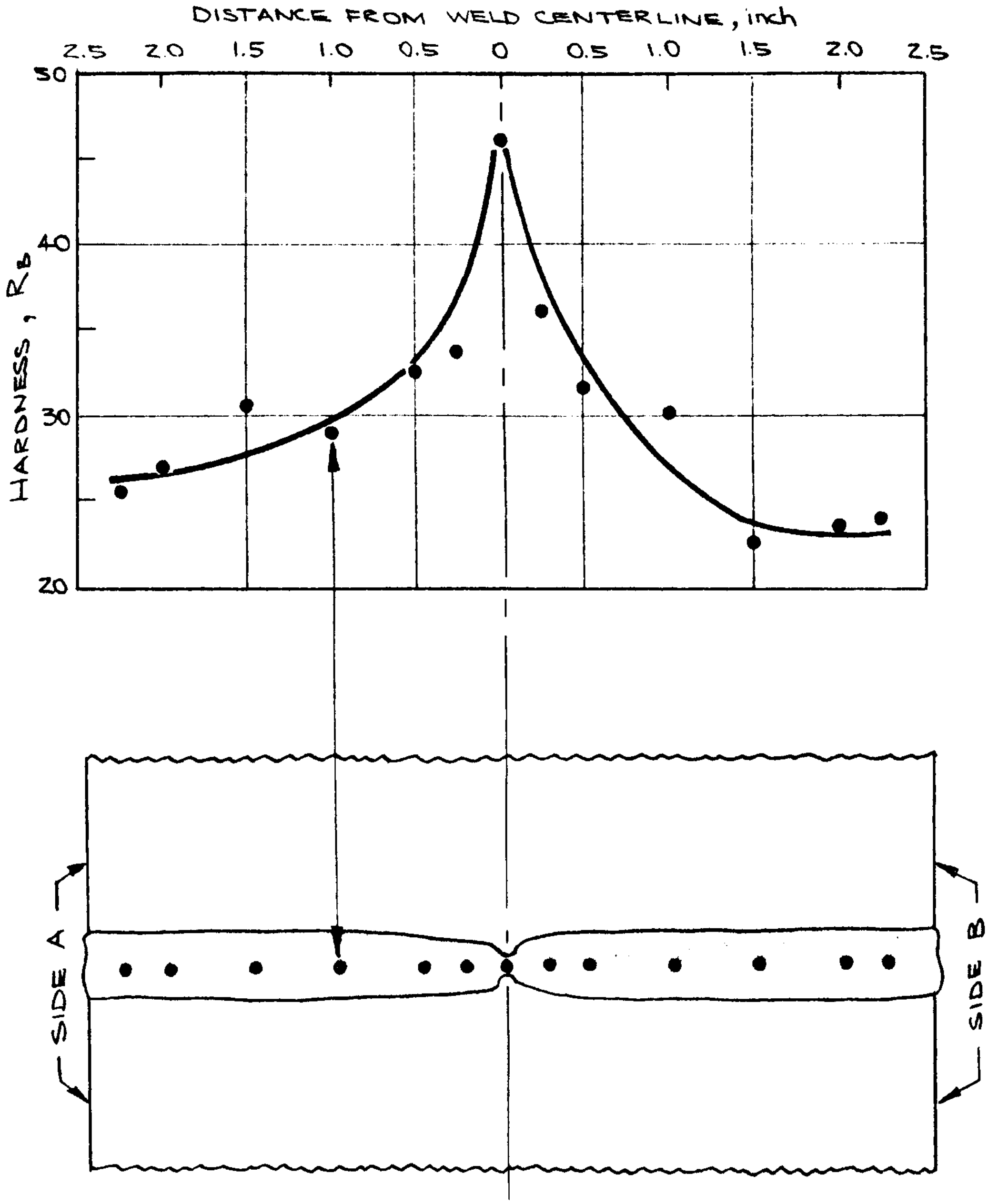


FIGURE 34. WELD METAL HARDNESS VARIATION IN 5-INCH-THICK 2219-T31 ALUMINUM NARROW-GAP WELDMENT – V20

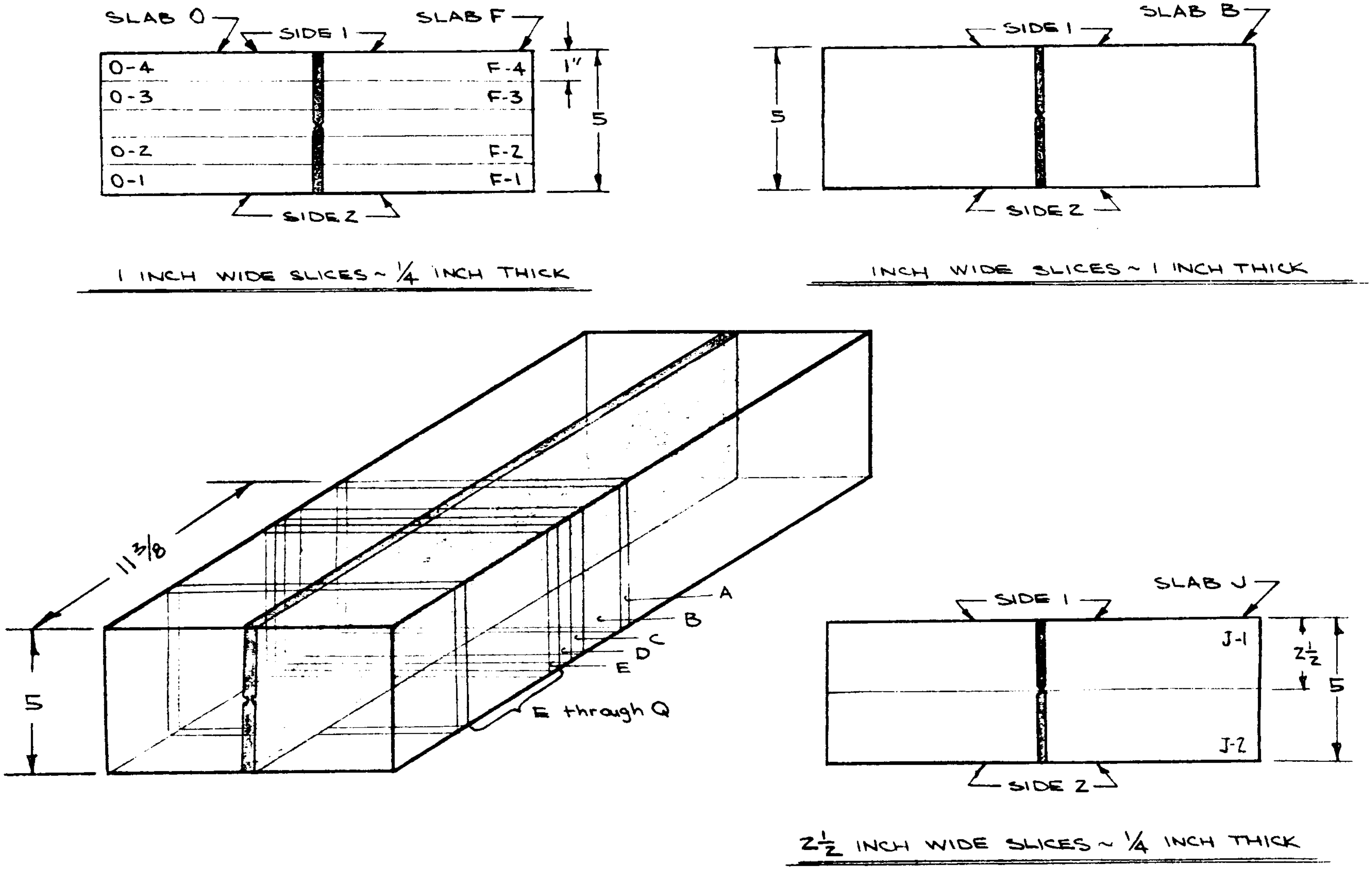


FIGURE 35. LOCATION OF TENSILE SECTIONS FROM WELD V-20

TABLE 6. ADDITIONAL TENSION TEST DATA - WELD V-20

Sample No.	Ultimate Strength, psi	Elongation, percent in 1/2 in.	1 in.	2 in.	Remarks
F-1[a]	43,400	8	5	2	Fusion line fracture Moderate porosity
F-2[a]	43,600	8	4	2	Center line fracture Slight porosity
F-3[a]	43,500	6	4	2	Fusion line fracture Slight porosity and lack of fusion
F-4[a]	49,000	10	5	2.5	Center line fracture Very clean
O-1[a]	38,200	6	4	2	Fusion line fracture Considerable porosity
O-2[a]	40,600	6	3	2	Fusion line fracture Very slight porosity and lack of fusion
O-3[a]	40,900	6	3	1.5	Fusion line fracture Very slight porosity and lack of fusion
O-4[a]	43,800	8	4	2	Center line fracture Very clean
J-1[b]	33,920	--	--	--	--
J-2[b]	33,950	--	--	--	--

(a) Aged after welding 24 hours at 325 F.
(b) Extra wide specimen.

CONCLUSIONS

(1) Type 2219-T31 aluminum plate in thicknesses up to 5 inches can be welded using the Narrow-Gap process.

(2) Procedures have been developed for welding 1- and 2-inch-thick 2219 alloy in the flat and horizontal positions using the single-wire-centered welding technique. These same procedures are believed to be applicable to welding 3-inch-thick plate in these positions.

(3) A twin-wire Narrow-Gap welding procedure has been developed for welding plate up to 5 inches thick in the vertical position. A similar twin-wire welding procedure was also used for welding 2-inch plate in the flat position. Based on the results obtained in welding 5-inch plate in the vertical position the twin-wire technique is believed to be suitable for welding 5-inch plate in the flat position.

(4) Using proper welding procedures, the radiographic quality level of Narrow-Gap welds will meet or exceed Grade 2 of MSFC-SPEC-359.

(5) The transverse-weld tensile strength of Narrow-Gap welds in 2219-T31 aluminum range from 40 to 42.2 ksi. Lack-of-fusion defects in the weld may cause a decrease in strength to as low as 31 ksi.

(6) Specially designed gas-shielding nozzles should be used in Narrow-Gap welding of aluminum. They are especially important when welding plates over 2 inches thick. A number of nozzle configurations were evaluated. An elongated nozzle which is held close to the plate surface and which has flexible end baffles extending into the joint was found to be most satisfactory.

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(4) Collins, F. R., "Porosity in Aluminum in Aluminum Alloy Welds", Welding Journal, 37 (6), pp 589-593 (1958).

* * * * *

The data on which this report is based are recorded in Battelle Laboratory Record Books Nos. 20716, pp 1-100; 20953, pp 1-13; 21180, pp 1-100; and 21625, pp 1-86.

DEC/RPM/REM/DCM:eh

APPENDIX A

TABLE A-1. WELD DATA – SINGLE WIRE CENTERED – FLAT POSITION

Spec. No.	Plate Dimensions, t x l x w, inch	Initial Joint Gap, inch	Wire Diameter, inch	Arc Current, ampere	Arc Voltage, volts	Wire Feed, ipm	Travel Speed, ipm	Gas Flow Rate Argon CFH	Gas Flow Rate Helium CFH	Head Angle, degrees	Contact Tube Gap, inch	No. of Passes	Weld Completion	Remarks
R-1	1 x 12 x 12	0.25	3/64	180	23	280	19	30	0	0	0.5	7	Yes	1
R-2	1 x 12 x 12	0.25			23			Varied	Varied			9		2
R-3	1 x 12 x 12	0.25			23			25	10			5	No	3
R-4	1 x 12 x 12	0.25			25/23			25	10			8	Yes	4
R-5	1 x 12 x 12	0.25			23			25	10			4	No	5
R-6	1 x 12 x 12	0.25						25	10			8	Yes	6
R-7	1 x 12 x 12	--		180/200				Varied	Varied			11		7
R-8	0.5 x 8.5 x 2	0.25		180				18	12			4		8
R-9	0.5 x 12 x 8	0.25						Varied	Varied			5		9
R-10	0.5 x 8.5 x 12	0.25				320		48	12			4		10
R-11	1 x 10 x 12	--				280		9	21	Varied		11		11
R-12	1 x 10 x 12	--						21	9			11		12
R-14	0.5 x 10 x 8	0.25		215	24	--	30	21	9	7		7		14
R-14A	2 x 24 x 14			220	22/24	--	30					4	No	14A
R-15	0.5 x 10 x 8			180	23.5	290	25					4	Yes	15
R-16	0.5 x 9 x 8			180	23.5		25					4		16
R-17	2 x 18 x 10			180/220	22/23		20					10		17
R-18	2 x 18 x 8			180/220	23							6	No	18
R-19	2 x 18 x 8			180	23/24			Varied	Varied			7		19
R-20	0.5 x 10 x 4			210	26	370	40	25	25			7	Yes	20
R-21	2 x 12 x 16			190/200	25		40/30					20		21
R-22	2 x 12 x 16			210/220	25		30					17		22
R-23	1 x 12 x 8	--		Varied	Varied	Varied		17.5	32.5			11		23
R-24	0.5 x 12 x 8	0.25		160	23	290						6		24
R-25	2 x 12 x 8			180		290	20/30					19		25
R-26	2 x 24 x 11			190/195		330/350	20/25					16		26
R-27	1 x 16 x 9			200/230	24/26	350/370	20/25					7		27
R-28	1 x 18 x 12			220/230	26	370	25					8		28
R-29	1 x 18 x 16			210/230	25							7		29
R-30	1 x 18 x 12			220	24							8		30
R-31	1 x 16 x 16			220/240	24	370/400						7		31
F-1	2 x 18 x 12			200/220	21/24	350/450		28	52		0.625	10	No	F1
F-2	2 x 18 x 10			190/215	21/24	400/420		21	39			13	Yes	F2
F-3	2 x 18 x 10			200/250	21.5/24	400/450						13		F3

TABLE A-1. (Continued)

Spec. No.	Plate Dimensions, t x 1 x w, inch	Initial Joint Gap, inch	Wire Diameter, inch	Arc Current, ampere	Arc Voltage, volts	Wire Feed, ipm	Travel Speed, ipm	Gas Flow Rate Argon, CFH	Gas Flow Rate Helium, CFH	Head Angles, degrees	Contact Tube Gap, inch	No. of Passes	Weld Completion	Remarks
F-4	5 x 16 x 8	0.25/0.50	3/64 & 1/16	200/280	20/25	420/330	25/45	21	39	7	0.625	26	No	F4
F-5	2 x 18 x 8	0.25	1/16	235/250	23/24.5	290/330	30/45					14	Yes	F5
F-6	5 x 16 x 8	0.312		250/280	23	290	35					1	No	F6
F-7	5 x 18 x 8			230	23	240						3	No	F7
F-8	3 x 18 x 10			280	25	290		28	52			5	No	F8
F-9	3 x 18 x 7			216/280	22.5/25	260/290	30					12	No	F9
F-10	3 x 18 x 7			240/280	23/26	290						28	Yes	F10
F-11	5 x 18 x 14			230/270	23/25	240/290						11	No	F11
F-12	5 x 18 x 14			230/280	23/24	290		21	39			11	No	F12
F-25	3 x 12 x 12			215	22	220	18	56	104			29	Yes	F25

Remarks - Table A-1

1. The arc wandered, and tended to crawl up the sidewalls of the joint, although it did not go out of control. A macrosection of the weld indicated that fusion was good.
2. Shielding gas mixture varied for different beads to see if the arc wandered less in other mixtures. Mixtures used - 20A-20He, 25A-10He, 10A-25He, 15A-25He, 20A-10He. One bead with 25A-10He failed to fuse to the sidewalls; three other beads deposited in the same mixture were easily controlled and appeared to fuse well.
3. To evaluate 25A-10He shielding gas mixture. Gap closed up and contact tube shorted out. No evaluation of shielding gas mixture could be made from this particular plate.
4. Repeated R-3, except first bead deposited with arc voltage of 25 volts. Arc appeared to be too long, unsteady, at 25 volts with this shielding mixture. Weld completed with arc voltage 23 volts. Weld was porous.
5. Repeated R-3. The arc was erratic and wandered in the joint while depositing the first and fourth beads. Welding was stopped after depositing four beads because of poor bead contour and lack of sidewall fusion.
6. Repeated R-3. The arc appeared to wander somewhat, but the beads appeared to fuse well. The average tensile strength of three 0.505 round transverse tensile bars were 23,800 psi with an elongation of only 1 percent in 2 inches. The tensile bars broke at the bond line, showing porosity and lack of fusion.
7. Bead-on-plate tests to check quality of welds in aluminum alloy with various combinations of argon and helium shielding gas. Using 30 cfh with 10 percent increments from 100 percent argon to 100 percent helium. Radiographs indicated beads deposited on plate were least porous when 60 percent A - 40 percent He shielding was used. The current changed from bead to bead, although the arc voltage and wire-speed setting were the same.
8. To evaluate 60 percent argon - 40 percent helium shielding gas mixture in Narrow-Gap weld in 1/2-inch-thick plate. The weld was completed, but the radiograph showed that it was extremely porous, especially at the sidewalls.
9. To evaluate the use of different volumes of shielding gas. The mixture was 80 percent argon - 20 percent helium. Volumes used were 40 cfh, 50 cfh, and 60 cfh. The beads appeared to have surface oxide when 40 cfh was used, but the bead appeared to be cleaner when the shielding gas volume was 60 cfh.
10. To further evaluate the use of 60 cfh shielding gas, using 80 percent argon. The weld beads appeared to be clean, but the radiograph showed the weld was porous.
11. Bead-on-plate tests to evaluate the effects of head angle. Head angle varied from 4 to 10 degrees. The beads deposited when the head angle was 7 to 10 degrees were wider. Another bead was run at 7 degrees head angle, 23-1/2 volts, 220 amperes. This bead was the least porous radiographically.
12. Repeated R-11, except for change in shielding gas, with head angle varied from 0 to 10 degrees. There was a flattening and widening of the beads when the head angle was increased. At 9 and 10 degrees, the beads were less uniform.
14. To evaluate the use of higher weld currents. The speed was raised to 30 ipm to allow for the increased weld-metal input. The radiograph showed that this was the least porous weld to date.
14a. Repeated R-14 in 2 inch plate. Fusion was not good at 22 volts, and arc wandered at 24 volts.
15. To develop conditions in 1/2-inch plate at 25 ipm travel speed. Results inconclusive because of slippage in wire-feed rolls.
16. Repeated R-15. Three of four passes ran well. The arc was erratic when the third pass was deposited. Weld was sound at the weld stop.
17. To develop conditions for welding in 2-inch-thick plate. The arc wandered to one side of the joint or the other.
18. Repeated R-17. The arc wandered. The wire jammed continually, so the wire-guide system was modified.
19. Repeated R-17, but varied shielding gas. Tried 21A-9He, 24A-6He, 9A-21He. The weld bead was on one plate, then the other.
20. Used 50 cfh shielding and higher voltage and current, with a faster travel speed. The weld looked good for some passes, but the arc wandered at times.
21. Started with conditions similar to those for R-20. The gap was filled better and fusion was better when the travel was slowed to 30 ipm. Some porosity, some lack of fusion.
22. Repeated R-21, except current was higher. The radiograph showed that the mid-length of the weld was clean, but there was porosity at the start.
23. Ran bead-on-plate tests to set preliminary conditions using 35A-65He.
24. Used conditions developed by bead-on-plate test, except voltage was one volt lower. The arc characteristics were different in the narrow groove. Fusion was poor.
25. Varied travel speed to establish proper speed for the conditions used. The fusion was marginal at all speeds used.

Remarks - Table A-1 (Continued)

26. Used higher current. The first 2 passes were at 20 ipm, the remaining at 25 ipm. The radiograph showed the weld was sound near the mid-length. The macrosection was not porous.

27. Continued tests using 65He-35A. The arc wandered when the voltage was 26 volts. Lack of fusion in spots.

28. Repeated R-27, keeping current higher. Some of the lack of fusion traced to misalignment of carriage.

29. Repeated R-27, this time using a backup bar with tighter fitup. (The bar was bent to make better contact with the plates). The arc wandered with the slightest misalignment of the contact tube.

30. Used a slightly lower voltage. The weld was sound except for lack of fusion at the root of the weld, between the plates and backup bar.

31. The current was turned to 240 for the first pass. The radiograph indicated that this weld was sound - Class 2 weld per MSFC-SPEC-259.

F-1. Weld in 2-inch-thick plate using currents in the spray transfer range. The beads tended to stay on one side of the joint, apparently because of improper wire lineup.

F-2. The first pass was not completely fused. It appeared that the shielding was inadequate. For the third weld pass, additional shielding gas was directed to the arc in 2 streams from 1/4 copper tubing leading and trailing the arc. This caused turbulence, and the weld bead was highly oxidized.

F-3. Repeated F-1. Current fluctuated, wire jammed continually, resulting in lack of fusion and porosity.

F-4. First weld in 5-inch-thick plate. The joint was a double-U, welded from both sides of the plate. Welding was done on alternate sides as required to control distortion. Used 1/16-inch diameter wire after welding to where joint tapered to 5/16 width. Weld cracked along sidewall on plate side B while welding on side A. There were 7 beads on side B, 19 beads on side A.

F-5. U-joint preparation, welding from one side. It was noted that at the bottom of the joint it was necessary to keep the voltage lower to control the arc and spread the bead. This difference in arc characteristics may have been caused by shielding gas differences, i.e., air in the deeper joints.

F-6. Weld in 5-inch-thick plate using 1/16-inch-diameter wire. Burned through 1/8-inch-thick machined land on first pass.

F-7. Bead appearance poor. (Dirty beads and lack of fusion). It appears that the gas coverage is inadequate.

F-8. Weld in 3-inch-thick plate using a slightly elongated shield, without diffuser plates. The shielding appeared to be inadequate.

F-9. Used another elongated gas shield, having a diffuser screen. Shielding was poor. Shielding was also poor when a standard nozzle was used. Shielding was worst with use of auxiliary with many holes drilled to disperse the shielding gas.

F-10. A box was built around the weld joint. The box was purged, then welding was done using a standard shielding nozzle.

F-11. Used a narrow duct to carry shielding gas into the joint. Welded from 2 sides, alternating every two passes. Weld beads were clean, and shielding appeared to be good. Deposited 11 passes. The weld cracked in the weld, near the sidewall on side B of plate while welding on side A.

F-12. Joint closed on shielding duct during welding. Welding stopped after 5 passes.

F-25. Used a shield with flexible end baffles in the joint. During welding the beads were clean and appeared to fuse well. Cross sections showed that there was some lack of fusion and porosity. The travel speed was relatively slow, and the current was low for 1/16-inch-diameter wire.

TABLE A-2. WELD DATA - SINGLE WIRE CENTERED - HORIZONTAL POSITION

Spec. No.	Plate Dimensions, t x l x w, inch	Initial Joint Gap, inch	Wire Diameter, inch	Arc Current, ampere	Arc Voltage, volts	Wire Feed, ipm	Travel Speed, ipm	Gas Flow Rate Argon, CFH	Gas Flow Rate Helium, CFH	Head Angle, degrees	Contact Tube Gap, inch	No. of Passes	Weld Completion	Remarks
H-1	1 x 14 x 10	0.25	3/64	200	23	290/350	20	17.5	32.5	7	0.5	7	Yes	H-1
H-3	1 x 7-1/2 x 3			200		350/400	20					6		H-3
H-4	1 x 14 x 8			200/220		400/450	25					7		H-4
H-5	2 x 16 x 8			210/240		400/450	25/35					16		H-5
H-6	2 x 9 x 6			220		400	25					14		H-6
H-7	2 x 18 x 8			--	19							1	No	H-7
H-8	2 x 12 x 8			230/240	23							12	Yes	H-8
H-9	2 x 18 x 16			220/240	24			28	52		0.625	12		H-9
H-10	2 x 18 x 16		1/16	220/240	23	240/290	35					15		H-10
H-11	2 x 18 x 12			220/250		240/290	30					11		
H-12	1 x 18 x 12			200/270		240/300	35/50					9		
H-13	1 x 18 x 12			200/240		240/300	35					9		

Remarks - Table A-2

H-1. Some lack of fusion at the upper sidewall of the horizontal joint. The contact tube shorted out. The welding head was braced to make it more rigid.

H-3. Repeated H-1. The radiograph indicated the weld was porous.

H-4. Used a higher current, while increasing the travel speed to control the larger puddle. This weld was less porous than the weld in Plate H-3.

H-5. Increased the current and travel speed for a number of passes. The weld beads deposited at 25 ipm appeared to be better.

H-6. Radiograph shows porosity along one side of weld.

H-7. The generator was improperly set on 19 volts. Fusion was poor.

H-8. There was some porosity along the upper side of the horizontal joint. The joint efficiency of this weld was 76 percent.

H-9. Used a cover plate over the joint, (around the end of the torch) to keep shielding gas in the joint. The weld was porous; the cover plate was not effective in improving shielding.

H-10. Tried 1/16-inch-diameter filler wire. The weld was porous. There was some lack of fusion in ingots.

TABLE A-3. WELD DATA - SINGLE WIRE CENTERED - VERTICAL POSITION

Spec. No.	Plate Dimensions, t x l x w, inch	Initial Joint Gap, inch	Wire Diameter, inch	Arc Current, ampere	Arc Voltage, volts	Wire Feed, ipm	Travel Speed, ipm	Gas Flow Rate Argon, CFH	Gas Flow Rate Helium, CFH	Head Angle, degrees	Contact Tube Gap, inch	No. of Passes	Weld Completion	Welding Direction	Remarks
V-1A	1 x 18 x 12	0.312	1/16	265	24	290	30	21	39	7	0.60	3	No	Up	V-1A
V-2A	1 x 18 x 12	0.312	1/16	200	24	190/220	26/32			15	0.625	4			V-2A
V-3A	1 x 18 x 12	0.280	3/64	200/224	23	360/400	25/30				0.625	4			V-3A
V-4A	1 x 12 x 6	0.280		200	25	360	27				0.375/0.50	8	Yes	Down	V-4A
V-1	1 x 18 x 12	0.312		220	21.5	345	30/38	22	38		0.625	7	No		V-1
V-2	1 x 18 x 12			220/260	21/22.5	280	37	21	39	5	0.500	12	Yes		V-2
V-3	1 x 18 x 12			240	23	280	47	22	38			10			V-3
V-4	2 x 18 x 12			216	22	--	37	21	39			3	No		V-4
V-5	2 x 18 x 12	0.280	1/16	240	21	190	37	35	65			6			V-5
V-7	5 x 16 x 14	0.312/0.375	1/16	240	22	240	37	35	65		0.562	15			V-7

Remarks - Table A-3

V-1A. Puddle flowed in joint - too large to control in vertical position.

V-2A. Although the weld pool was too large and sagged in the joint, the bead would not spread to the sidewalls of the joint.

V-3A. Tried vertical weld using smaller wire. Although beads on plate spread to 3/8-inch width, these beads would not fuse consistently to the sidewalls of the 9/32-inch-wide joint. The weld beads sagged and rippled excessively.

V-4A. Different CTWD's were used. The contact tube shorted out when CTWD was 3/8 inch. Used higher voltages for this weld in attempts to spread the bead. There was still lack of fusion. Joint closed to 1/4 inch, but fusion still was not good.

V-1. Welded vertically down in attempts to spread the weld bead. Head at first tilted up to control the puddle, but puddle ran down on the wire even at 38 ipm. When the head was tilted down, the puddle spread well, but fusion was poor.

V-2. Head angle of 5 degrees was used. Fusion appeared to be better.

V-3. Used an increased travel speed. Bead spread well, fusion good in some beads. Shielding was poor. (It was found later that these beads were porous.)

V-4. Various shields tried.

V-5. Used larger wire to weld vertically down. The joint appeared to be well filled. (The weld was later found to be porous.) Contact tube shorted out as joint closed up.

V-7. Used conditions from V-5 to weld a 5-inch-thick plate. Peened the weld after each pass, but the weld cracked on one side (in the weld centerline) while welding being done on the other. A total of 15 passed had been deposited on alternate sides of the plate. A macrosection showed that the beads were extremely porous.

TABLE A-4. WELD DATA - TWIN WIRE - FLAT AND VERTICAL POSITIONS

Spec. No.	Plate Dimensions, t x l x w, inch	Initial Joint Gap, inch	Wire Diameter, inch	Arc* Current, ampere	Arc* Voltage, volts	Wire* Feed, ipm	Travel Speed, ipm	Gas Flow Rate Argon, CFH	Gas Flow Rate Helium, CFH	Head Angle, degrees	Contact Tube Gap, inch	No. of Passes	Weld Completion	Position	Welding Direction	Remarks
F1-1	1 x 16 x 7-3/4	0.375	3/64	160	22	295	40	28	52	5	0.50	11	Yes	Flat	--	F1-1
				160	22	295										
F2-2	1 x 16-1/2 x 7-3/4			160	22	300						8			--	F2-1
				--	22	290										
F3-1	1 x 16 x 7			175	22	350						9			--	F3-1
				--	21	290										
RE-6	5 x 15 x 7			180	21	425	37	56	104			17			--	RE-6
				185	22	375										
F-24	2 x 12 x 12			180	21	365						14			--	F-24
				180	22	350										
F-26	2 x 12 x 12			180	21	365	40					18			--	F-26
				185	22	340										
RE-5	5 x 13 x 6			160	19	370						6	No	Vertical	Up	RE-5
				160	19	370										
RE-7	5 x 15 x 8			200	21	450	32					14	Yes			
				190	23	335/300										
F-27	3 x 12 x 12			160	20	365	40					30				F-27
				170	21	315										
RE-8	5 x 25-3/4 x 14			175	20	365	45					26				RE-8
				170/185	19	345										
V-19	5 x 27 x 24	0.375/0.438		180	--	385	43					53	No			V-19
				175	--	345										
RE-9	5 x 15 x 8	0.375		190	23	390	37/43					13				RE-9
				180	19	365/335										
V-20	5 x 22 x 22	0.375/0.438		190	21.5	335	40					59	Yes			V-20
				180	20	315										

*Top value in each set is for lead wire, bottom value is for trail wire.

Remarks - Table A-4

F1-1. Welds made to develop twin-wire conditions. Radiograph showed porosity and lack of fusion along the side welded by the trailing wire.
F2-1. Increased speed of leading wire to increase preheating of joint for trail wire. There was only fine scattered porosity - heavier near the sidewall.
F3-1. Again increase feed speed of leading wire. Sidewall wash was improved for both wires. There was little porosity in this weld except at starts.
RE-6. To test the twin-wire technique to see if welds could be deposited under restrained conditions without cracking. There was lack of fusion in some beads, but the plate did not crack.
F-24. This plate was completed and tested. The tensile strength was good. (See Effects of Preheat in body of the report).
F-26. This plate was preheated to 300-350 F. Fusion was very good, mechanical properties were good. (See Effects of Preheat).
RE-5. Welded prior to RE-6, but in the vertical position. Over 5/8 inch depth of weld deposited without cracking. Welding stopped because equipment was scheduled for another project.
RE-7. Welded prior to RE-6, but in the vertical position. Over 5/8 inch depth of weld deposited without cracking. Welding stopped because equipment was scheduled for another project.
F-27. Repeated RE-5. This weld cracked.
RE-8. Repeated RE-5, except currents were higher. This weld was completed. The macrosections of this weld indicated that the weld was sound.
V-19. Plate cracked. Voltmeter found to be inaccurate, recalibrated.
RE-9. This plate was used to check welding conditions.
V-20. Very good weld although there was slight lack of fusion.

TABLE A-5. WELD DATA - SINGLE WIRE OFFSET - VERTICAL AND FLAT POSITIONS

Spec. No.	Plate Dimensions, t x l x w, inch	Initial Joint Gap, inch	Wire Diameter, inch	Arc Current, ampere	Arc Voltage, volts	Wire Feed, ipm	Travel Speed, ipm	Gas Flow Rate Argon, CFH	Gas Flow Rate Helium, CFH	Head Angle, degrees	Contact Tube Gap, inch	No. of Passes	Weld Completion	Position	Welding Direction	Remarks
V-8	2 x 12 x 12	0.375	1/16 & 3/64	170/200	21	210/300	45/37	27	52	5	0.5	16	Yes	Vertical	Up	V-8
V-9	5 x 13 x 10	0.375/0.438	1/16	175/200	21.5/23	--	37	35	65	5		5	No			V-9
V-10	5 x 22 x 12			175/200	21.5/22	205/240	39	52	100	7		109	Yes			V-10
V-11	5 x 13 x 12			185/240	21.5	210/270	48			7		8	No			V-11
V-12	5 x 13 x 11	0.438		200	20.5/22	210/245	48			5		29				V-12
V-13	1 x 12 x 11	0.375		170/200	20.5/21	185	33	21	39			16	Yes			V-13
V-14	1 x 12 x 11			160/200	21/22	185/215	35					6	No			V-14
V-15	1 x 12 x 11			170	21	190/205	35					6				V-15
V-16	1 x 12 x 13			150/185	21	205/210	33	28	52			6				V-16
V-17	1 x 12 x 9			170/200	21.5	210/300	33					7				V-17
V-18	1 x 12 x 9			170/200	21/22	310	35					6		Flat	--	V-18
RE-1	5 x 13 x 6			190	22	235/310	36					8			--	RE-1

Remarks - Table A-5

V-8. Different travel speeds used to develop conditions for fillet-type beads.

V-9. Beads deposited vertically down were too wide for fillet-type beads. Conditions were developed for single-wire-offset vertically up.

V-10. Using conditions similar to those set in V-9, a 5-inch-thick plate was completed, but found to be cracked.

V-11. Joint closed up to 5/16 - too narrow for single-wire-offset technique using those welding conditions (a fillet was deposited on one side, but the bead also spread to the other sidewall, but was unfused).

V-12. An electric-power driven wire brush was used for interpass cleaning on side 1 to see if this would improve the welds; however, the weld cracked on side 1.

V-13. Welds V-13 through V-18 were made to study the effects of different variables on porosity in welds. Radiographs were made of all of these welds. V-13, welded in a purge box was less porous than welds made in the open.

V-14. Standard nozzle used. This weld was porous.

V-15. Preheated to 175 F, welded in purge box. Preheating affected porosity level very little.

V-16. Rough bead - not evaluated for porosity.

V-17. Welded in purge box, radiographed after 6 passes. Some lack of fusion.

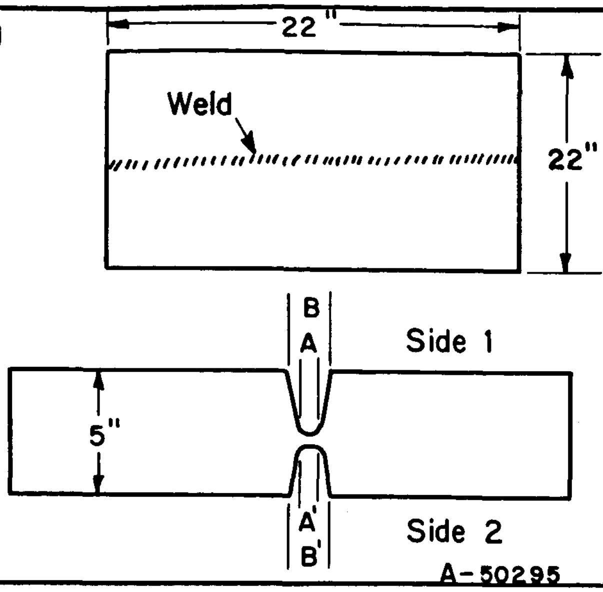
V-18. Deposited in flat position - these conditions caused porous welds in the flat position.

RE-1. Restraint specimen welded in purge box. Weld cracked after 8 beads had been deposited.

APPENDIX B

METALS JOI
ARC-WELDI

DIAGRAM



Type of Welding: Narrow Gap
Purpose of Test: (1) Final Ch
(2) Determi
(3) Provide I

BASE MATERIAL: 2219
Condition: T31
Size: 5 x 22 x 22
Cleaning, initial: Standard

Cleaning, interpass: Standard
Jigging: None

		Electrode or Filler Wire			Shielding Gas			Shielding Gas		Temperature				Welding Current		Arc Voltage			
	Pass	Type	Brand	Size, inch	Type	Flow, cfh		Type	Flow, cfh	Preheat, F	Interpass, F	Postheat, F	Time at Postheat, min	Lead Wire, amp	Trail Wire, amp	Lead, volts **	Trail, volts	Arc Ti	
	1	2319		3/64	He	52		A	28	65	--			200	--	21.5	--	.75	0.
*	2										--			190	--	21.5	--		
	3									65	--			190	160	21.3	19.0		
	4										--			180	160	21.3	19.8		
	5										--			180	168	21.3	19.0		
	6										--			180	172	21.0	19.0		
	7										--			175	168	21.0	19.0		
*	8										--			170	176	21.0	19.0		
	9									72	85			180	164	21.0	19.0		
	10										max			175	164	21.0	19.0		
	11													170	160	21.0	19.0		
	12													170	168	21.0	19.0		
	13													175	172	21.0	19.0		
	14													175	172	21.0	19.3		
	15													175	172	21.0	19.5		
	16													175	168	21.0	19.5		
	17													175	168	21.0	19.3		
	18													175	168	21.0	19.3		
	19													175	168	21.0	19.0		
	20													175	168	21.0	19.0		

*Arrows indicate cooling to room temperature. Generally overnight breaks before resuming welding.

ING DIVISION
G TEST DATA

Project: G-6689
Sheet: Lot 2
Specimen: V-20
Date: 12-21-64
12-23-64

Manual ☐ Automatic ☑

ck on 5" t Vertical Parameters
e Joint Shrinkage
laterial for Test Specimens

ELECTRICAL:

Power Source: Vickers C. P. 324-96, 324-97
Welding Machine: BMI Positioner 324-79
Automatic Control: Airco AMC-C, # 145
" " ", # 146
Meters Used: E. A. Recorder, 324-49
Special Equipment: 1-1/4-inch Wire Spacing. Wire end positioned 1/16 inch from sidewall
Electrode Polarity: Reverse

FOR TIG WELDING:

Electrode Type
Electrode Size
Cup

OTHER EQUIPMENT

Initial Gap Dimensions, inch

A - .397
A1 - .393
B - .470
B1 - .451

Vertical up

**All Lead Wire Voltage Readings 2 Volts High

, min	Contact Tube to Work Distance, in.	Lead Wire Feed Rate, ipm	Rate of Travel, ipm	Trail Wire Feed Rate, ipm	Plate Side	Joint Gap, inch Weld Surface A, Side 1	A1, Side 2	Plate Surface B, Side 1	B1, Side 2	Remarks
	5	380	40	--	1	.370	.368	.440	.430	Single wire centered passes for
		380		--	2	.358	.353	.432	.415	root fusion
		380		335	1	.340	.342	.400	.420	
		365		335	2	.338	.330	.422	.376	
		365		345	1	.341	.330	.380	.407	Trail shield extension stuck on spatter - may have
		365		345	2	.330	.330	.417	.365	aspirated some air
		355		330	1	--	--	--	--	
		345		330	2	.325	.317	.401	.355	
		345		320	1	.323	.323	.376	.383	
		335		320	2	.322	.317	.392	.367	
		335		320	1	.317	.319	.380	.380	
		335		320	2	.318	.320	.388	.365	
		335		320	1	.321	.319	.375	.378	
		335		320	2	.322	.322	.385	.367	
		335		320	1	.320	.323	.379	.375	
		335		320	2	.320	.320	.384	.373	
		335		320	1	.322	.320	.377	.375	
		335		320	2	.322	.321	.377	.372	
		335		320	1	.325	.321	.376	.375	
		335		320	2	.325	.324	.377	.373	Shrinkage about nil now. Weld surface 1.5 inch from plate surface.

Recorded by ______ Observed by ______

			Electrode or Filler Wire			Shielding Gas			Shielding Gas		Temperature				Welding Current		Arc Voltage		
	Pass	Type	Brand	Size, inch	Type	Flow, cfh		Type	Flow, cfh	Preheat, F	Interpass, F	Postheat, F	Time at Postheat, min	Lead Wire, amp	Trail Wire, amp	Lead, volts **	Trail, volts	Arc Time,	
*	21	2319		3/64	He	52		A	28	65	85			175	168	21.0	19.0	.75	0.5
	22										max			175	168	21.3	19.5		
	23													175	168	21.3	19.5		
	24													175	168	21.3	19.0		
	25													175	168	21.3	19.5		
	26													175	168	21.3	19.5		
*	27									65	125			175	168	21.5	19.8		
	28										max			175	168	21.5	19.8		
	29													175	168	21.5	20.0		
	30													175	172	21.5	20.0		
	31													180	168	21.5	19.5		
	32													180	172	21.5	19.5		
	33													180	172	21.5	19.5		
	34													180	168	21.5	19.5		
	35													180	176	21.5	19.5		
	36													180	176	21.5	20.0		
	37													185	180	21.5	19.5		
	38													185	180	21.5	19.5		
	39													185	180	21.5	19.5		
	40													180	176	21.5	19.5		
	41	2319		3/64	He	52		A	28		125			180	176	21.5	19.5	.75	0.
	42										max			190	172	22.0	20.0		
	43													190	172	22.0	20.0		
	44													190	172	22.0	20.0		
	45													190	180	22.0	20.0		
	46													190	180	22.0	20.0		
	47													190	168	21.8	20.0		
	48													190	180	22.0	20.3		
	49													190	180	22.0	20.3		
	50													190	172	22.0	20.5		
	51													190	168	22.0	20.5		
	52													190	168	22.0	20.8		
	53													190	160	22.0	20.5		
	54													180	160	22.0	20.5		
	55													180	160	22.0	20.5		
	56													180	160	22.0	20.5		
	57													180	160	22.0	20.5		
	58													180	--	22.0	--		
	59													180	--	22.0	--		

**All Lead Wire Voltage Readings 2 Volts High					Joint Gap, inch				
					Weld Surface		Plate Surface		
Contact Tube to Work Distance, in.	Lead Wire Feed Rate, ipm	Rate of Travel, ipm	Trail Wire Feed Rate, ipm	Plate Side	A, Side 1	A[1], Side 2	B, Side 1	B[1], Side 2	Remarks
	335	40	320	1	.326	.324	.377	.374	
	335		320	2	--	--	--	--	
	335		320	1	.332	.325	.376	.374	
	335		320	2	--	--	.376	.374	Contact tube arc to joint. Ground and rewelded
	335		320	2	--	--	.376	.374	
	335		320	1	--	--	.376	.374	
	335		320	1	.340	.330	.376	.370	
	335		320	2	--	--	.376	.370	
	335		320	2	--	--	.376	.370	
	335		320	2	--	--	.376	.370	Contact tube arc to joint. Ground and rewelded. Installed
	335		320	2	--	--	.376	.370	new contact tube, possible lack of fusion
	335		320	1	--	--	.376	.370	
	335		320	1	--	--	.376	.370	
	335		320	1	--	--	.376	.370	
	335		320	1	--	--	--	--	
	335		320	2	.347	.338	.375	.369	
	335		320	2	--	--	--	--	
	335		320	2	.347	--	--	--	
	335		320	2	--	--	--	--	
	335		320	1	.347	--	.372	.366	Side 2: 1/2 inch from surface
	335	40	320	1	.347	--	--	.366	
	335		320	1	.347	--	--	.366	
	335		320	1	.347	--	--	.366	Side 1: 1/2 inch from surface
	335		320	2	.347	--	--	.366	
	335		320	2	.347	--	--	.366	
	335		320	2	.347	--	--	.366	
	335		320	2	.347	--	--	.366	
	335		320	1	.347	--	--	.366	
	335		320	1	.347	--	--	.366	
	335		320	1	.347	--	--	.366	
	335		320	1	.347	--	--	.366	
	335		320	1	.347	--	--	.366	
	335		320	1	.347	--	--	.366	
	335		320	2	.347	--	--	.366	
	335		320	2	.347	--	--	.366	
	335		320	2	.347	--	--	.366	
	335		320	2	.347	--	--	.366	
	335		320	2	.347	--	--	.366	Single wire centered pass
	335		320	2	.347	--	--	.366	

Recorded by ______________________ Observed by ______________________